ECONOMIC GEOLOGY

VOL. XVII. JUNE–JULY, 1922. No. 4

KANSAS STATE AGRICULTURAL COLLEGE JUN 17 1922 LIBRARY

REFLECTED BURIED HILLS AND THEIR IMPORTANCE IN PETROLEUM GEOLOGY.

SIDNEY POWERS.[1]

CONTENTS.

Nomenclature 233
Examples 235
Nemaha Mountains 237
Cushing Field 237
Sand Springs-Inola-Spavinaw 243
Healdton Field 243
Robberson Field 244
Red River Uplift 246
Wichita Mountains 246
Amarillo Hills 248
New Mexico Examples 249
Tamasopo Ridge 250
Origin 251
Type of Folding 252
Hypotheses 252
Conclusions 253
Importance to Petroleum Accumulation 257
Discovery 258

DISCOVERY.

In the autumn of 1914, two wells drilled in east central Kansas encountered granite at depths of 900 feet or more where a nor-

[1] Published by permission of the Amerada Petroleum Corporation. The writer is indebted to Mr. E. DeGolyer for suggesting the preparation of this paper and for contributing examples. He also wishes to express appreciation for very careful criticism to Mr. Wallace E. Pratt and Professor Eliot Blackwelder and for helpful suggestions to Professor J. B. Woodward and Charles Schuchert and to Mr. F. C. Greene, Mr. Richard Hughes, Mr. E. W. Scudder and Mr. W. E. Hubbard.

mal succession of Pennsylvanian and older sediments was expected to a depth of at least 2,500 feet. The granite was not identified as such in the first examination of the cuttings and a year elapsed before geologists realized that it represented a ridge of hills of pre-Cambrian rock unconformably buried by the Paleozoic sediments. Many other wells in and near the Mid-Continent oil fields have since been drilled into the pre-Cambrian terrane and most of them have revealed buried hills and ridges the presence of which is manifested by the structure in the surface strata.

Superposition of surface anticlines over buried topographic eminences has scarcely been considered in geological literature, yet both the tectonic and economic phases of the relationship merit discussion. The tectonic problem is to account for the superimposed structure. The economic problem is to explain the intimate association of petroliferous deposits with buried topography.

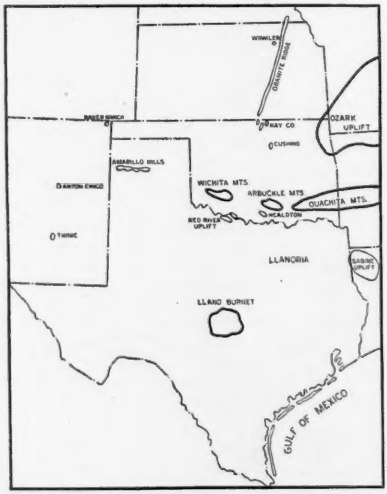

FIG. 28. Map of Kansas, Oklahoma, Texas and New Mexico, showing the location of buried hills and ridges in relation to uplifts and mountain-built areas.

Discussion is limited to the "Granite ridge" (Nemaha Mountains) of Kansas and associated areas in Kansas and Oklahoma, Cushing field, Healdton field, Wichita Mountains, Red River uplift and the buried hills in the Texas Panhandle and in New Mexico (see Fig. 28), with mention of other possible examples as the Tamasopo ridge in Mexico. The oil fields and prospects on both sides of the Red Sea may be on the flanks of uplifted buried ridges, but the descriptions in the Petroleum Research Bulletins of the Ministry of Finance, Egypt, do not make the relationships clear.

In the entire Mid-Continent region the surface strata are tilted in homoclinal manner at an angle of 10 to 150 feet to the mile (⅛ degree to 2 degrees), the average dip being about 50 feet to the mile. Folds consist of anticlines, domes, terraces, noses and minor flexures. The smaller closed structures seldom have a closure of more than 20 feet, but the larger ones sometimes have a closure of 100 feet. Their length is from less than 1 mile to 10 miles or more.

NOMENCLATURE.

Geologic maps of the United States and Europe show small areas of pre-Cambrian basement surrounded by sediments unconformably superimposed and dipping quaquaversally. These are gigantic domes or fault blocks which have risen with respect to the surrounding area and which have been unroofed by subsequent erosion. Other similar domes and fault blocks, not yet unroofed, are known. From these major structural features there are all gradations to the buried hills here described.

Suess in Das Antlitz der Erde introduced the classification of block faults, horsts for upraised and graben for downthrown blocks. Unfortunately he did not introduce a similar couplet for analogous areas of periodic upwarp and downwarp. He used the terms positive and negative with reference to tide-gauge readings and applied them to the movement of the sea relative to the land. A falling tide reads downward on a tide-gauge and is negative, a rising tide reads upward and is a positive movement.

Hence, a rising of the land relative to the sea was negative and a sinking of the land, positive.

American literature has reversed the usage and these terms are applied to land areas. A positive element is a segment of the earth's crust which tends to rise or to remain stable, while adjacent segments tend to sink. Because the original usage has been forgotten and the other generally accepted, it seems advisable to follow the American usage and to apply the terms to areas of lithological or structural entity. The Cincinnati and Nashville arches, the Black Hills, and the Llano Burnet (Central Mineral) region of Texas are examples of positive elements. The writer has similarly classed the Sabine uplift of Louisiana.[2] The Preston anticline,[3] which extends from Oakland and Madill, in Oklahoma, across the Red River at Preston Bend and north of Denison and Bonham, Texas, is a similar rejuvenation in Cretaceous sediments of a folded Paleozoic geanticlinal area.

A positive element is a geological unit and is a major structural feature. The minor structural features with which this paper deals are reflections of buried topography, not geology. For example, the Sabine uplift has acted as a unit geologically. It has stood as a structural plateau against and in which tangential compressive forces have acted. It is a positive element, not a buried hill. Its surface, however, is a series of minor folds some of which may reflect buried topography.

Reflected buried hills are, then, topographic units reflected in structure of overlying sediments. Buried hills uncovered by erosion have been called "baraboos" from the Baraboo Hills of Wisconsin.[4] A striking example which shows that buried hills are

[2] "The Sabine Uplift, Louisiana," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 2, pp. 117–36, 1920. The terms positive and negative were introduced by Bailey Willis, "A Theory of Continental Structure Applied to North America," Geol. Soc. Amer., *Bull.*, vol. 18, pp. 389–412, 1907.

[3] O. B. Hopkins, Sidney Powers and H. M. Robinson, "Structure of the Madill-Denison Area, Oklahoma and Texas, with Notes on the Oil and Gas Development in that and Adjoining Areas," U. S. Geol. Survey Bull. 736A, 1922.

[4] F. H. Lahee, "Field Geology," 1916, p. 322 defines a baraboo as "a mo-

simply buried monadnocks is the Wichita Mountains[5] with rounded peaks entirely exposed in the Mountains proper, partly exposed at the edge of the Mountains and farther away completely covered by horizontal sediments.

EXAMPLES.

Nemaha Mountains.—The buried Nemaha Mountains of Kansas[6] extend from Pawnee County, Nebraska, through the Eldorado and Augusta fields of Butler County, Kansas, a distance of 218 miles (Fig. 29). They probably extend with intervening saddles through Kay and Noble Counties, Oklahoma, a further distance of 48 miles. From a depth of 550 feet (675 feet above

nadnock which has been buried by a series of strata and subsequently reexposed by the partial erosion of these younger strata." An example of a baraboo is described by H. E. Gregory, "Geology of the Navajo Country" (Quartzite Creek), U. S. Geol. Survey, Prof. Paper 93, 1917; others on the east side of the Estancia Valley, New Mexico, are described by J. L. Rich, Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, p. 329; *idem*, vol. 5, no. 5, pp. 605–8.

[5] J. A. Taff, "Preliminary Report on the Geology of the Arbuckle and Wichita Mountains, in Indian Territory and Oklahoma," U. S. Geol. Survey, Prof. Paper 31, 1904.

[6] F. W. Russell, (note) *Am. Geol.*, vol. 1, pp. 130–1, 1886; B. P. Russell, Sixth Biennial Rep. Comm. of Public Lands and Buildings to Governor of Kansas, 1888, pp. 57–84; R. Hay, "Note on the Occurrence of Granite in a Deep Boring in Eastern Kansas," Kan. Acad. Sci., Trans. 13, pp. 75–76, 1893; J. E. Todd, (note) *Am. Geol.*, vol. 15, p. 64, 1895; N. H. Darton, Preliminary Report on the Geology and Underground Water Resources of the Central Great Plains, U. S. Geol. Surv., Prof. Paper 32, pp. 283–84, 1905; E. Haworth, "On Crystalline Rocks in Kansas," Univ. Geol. Surv. Kansas, Bull. 2, 1915; C. H. Taylor, "The Granites of Kansas," Southwestern (Am.) Assoc. Petroleum Geologists, *Bull.*, vol. 1, pp. 111–26, 1917; Sidney Powers, "Granite in Kansas," *Am. Jour. Sci.* (4), vol. 44, pp. 146–50, 1917; Park Wright, "Granite in Kansas Wells," Am. Inst. Min. Engrs., Bull. 128, pp. 1113–30, 1917; R. C. Moore and W. P. Haynes, "The Crystalline Rocks of Kansas," in "Oil and Gas Resources of Kansas," Geol. Surv. Kan., Bull. 3, 1917; R. C. Moore, "Geologic History of the Crystalline Rocks of Kansas," Am. Assoc. Petroleum Geologists, *Bull.* 2, pp. 98–113, 1918; "The Relation of the Buried Granite in Kansas to Oil Production," *idem*, vol. 4, no. 3, pp. 255–63, 1920; "Buried Granite and Kansas Oil Output," *Petroleum Mag.*, July, 1920, pp. 100–3; A. E. Fath, "Geology of the Eldorado Oil and Gas Field," State Geol. Survey of Kansas, Bull. 7, 1922.

sea level) in Pawnee County, Nebraska, and 586 feet (564 feet above sea level) in Nemaha County, Kansas, the surface of the granite becomes gradually lower until in the Towanda pool of the

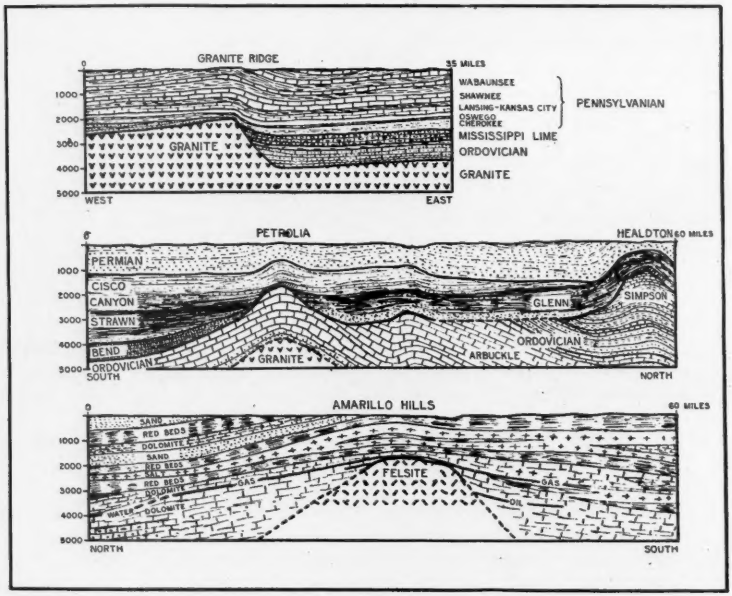

FIG. 29. Cross-section of the Granite Ridge of Kansas, the Petrolia and Healdton fields of Oklahoma and Texas, and the Amarillo Hills of Texas showing reflected buried hills. Constructed from well logs with same horizontal scale and vertical exaggeration. The Kansas section extends from sec. 19, T. 18 S., R. 6 E., to sec. 8, T. 23 S., R. 9 E. The Petrolia-Healdton section extends from Henrietta, Texas, to north side of Healdton field. The Amarillo section shows a series of unnamed Permian beds with a gas-bearing horizon covering the buried hill of felsite and a reported showing of oil on the south flank of the hill. A new well on the north flank shows a great thickness of arkose instead of dolomite as here shown and the slope of this flank is probably more gentle than shown.

Eldorado field it is 300 feet below the producing sand (1,275 feet below sea level) and in Sumner County, 21 miles north of the Oklahoma line, it has been found at a depth of 3,420 feet (2,230

feet below sea level). A total of 28 wells are reported to have encountered granite or schist along this ridge, while many tests to greater depths on either side have found no granite.[7]

The first well to encounter granite was drilled in 1886, near Bern, Nebraska, and others were drilled later but no especial attention was given them until tests for oil were started.

Topographically the mountains consist of gentle ridges and low hills from one mile to five miles wide on top. The summits gradually become lower toward the south. The maximum proved relief is 1,400 feet in about 4½ miles (4 degrees) on the eastern side in T. 10 S., R. 10 E., 55 miles south of the Nebraska state line, and is equally or probably more pronounced near Cottonwood Falls in T. 19–20 S., R. 7 E. In general, the relief on the eastern flank of the Mountains is believed to be the steeper, from 500 to 1,000 feet or more in six miles (1 degree to 2 degrees), and that on the western flank the gentler, from 300 to 600 feet in the same distance (approximately the normal surface dip). East of the ridge there is probably a broad topographic valley in the surface of the pre-Cambrian rocks about 10 to 15 miles from the crest of the ridge, corresponding with the regional structural syncline in the surface strata (Fig. 29).

The strike of the Pennsylvanian formations exposed at the surface is approximately parallel to the ridge. Underground, the buried mountains are in contact with the highest Pennsylvanian formation in Kansas at their northern end and the lowest Pennsylvanian formation at their southern end; the intervening columnar section is 2,000 feet thick. The underlying Paleozoic formations are also cut off to the north and cover the granite only at

[7] The following is a list of wells along the Mountains which have reached granite, the location being section, township, range, with depth of top of granite in feet: Nebraska, 29-3-12, 600; 6-2-12, 600; 25-1-12, 552; Kansas: 34-2-12, 586; 34-6-11, 960; 12-10-10, 2,300; 28-10-9, 928; 26-10-9, 958; 1-11-9, 1,180; 24-15-7, 2,512; 11-16-7, 1,900; 34-17-7, 2,506; 5-18-6, 2,515; 15-18-6, 2,427; 19-18-6, 2,410; 4-18-7, 2,110; 7-19-6, 2,585; 34-19-7, 1,805; 25-20-5, 3,040; 2-20-7, 1,890; 7-22-4, 3,355 (schist); 14-23-5, 2,331; 16-23-5, 2,735; 26-23-5, 2,545; 11-26-4, 2,675; 12-26-4, 2,805; 17-28-4, 2,800; 36-31-2, 3,420.

the southern end of the ridge, in the Eldorado and Augusta fields. The normal Paleozoic section includes limestone of Mississippian age (the "Mississippi lime" in part), black and green shales and oil sands (Mounds or "Wilcox" Sand) of the Tyner formation of Ordovician age, and siliceous limestone of Cambro-Ordovician age.[8] The siliceous limestone is of variable thickness depending on the irregularities in the pre-Cambrian floor, but an average thickness is 600 to 1,000 feet. The pre-Cambrian rocks are pink, rarely gray, granites and schists.[9] Several of the deep wells elsewhere in Kansas which are not known to have reached granite encountered sedimentary formations below the Cambro-Ordovician which are probably of pre-Cambrian age.[10] Conglomerate is rarely reported in logs of granite wells because the mountains covered too limited an area to support permanent streams. The coarse conglomerate from which oil is produced on the Sinclair Oil & Gas Co. lease at Peabody is exceptional and is several hundred feet stratigraphically above the granite, but in a horizon which abuts the granite in the ridge on the east.

No pre-Pennsylvanian sediments are exposed in the Great Plains synclinorium west of the Ozark uplift or, roughly, west of Missouri and eastern Oklahoma. Mississippian and Ordovician strata overlie this uplift, and their continuity is interrupted by only a few "windows" of the pre-Cambrian granite. The

[8] The interpretation of stratigraphy is that introduced by F. L. Aurin, G. C. Clark and E. A. Trager, "Notes on the Subsurface pre-Pennsylvanian Stratigraphy of the North Mid-Continent Fields," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, pp. 117–53, 1921.

[9] Granite boulders are found on the surface in an area not exceeding 160 acres in Woodson County; W. H. Twenhofel, "Granite Boulders in the Pennsylvanian of Kansas," *Am. Jour. Sci.* (4), vol. 43, pp. 363–80, 1917; "Additional Facts Relating to the Granite Boulders of Southeastern Kansas," *ibid.*, vol. 48, pp. 132–5, 1919; "The Silver City Quartzite," Geol. Soc. Amer., *Bull.*, vol. 28, pp. 419–30, 1917; R. C. Moore and W. P. Haynes, "An Outcrop of Basic Igneous Rock in Kansas," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 2, pp. 183–7, 1920; W. H. Twenhofel and E. C. Edwards, "The Metamorphic Rocks of Woodson County, Kansas," *idem*, vol. 5, no. 1, pp. 64–74, 1921.

[10] As the Okla. Prod. & Ref. Co. Stevenson well, sec. 5, T. 24 S., R. 14 E., which found black sand, shale and lime from 2,915 to 3,557 feet.

nearest of these to the Mid-Continent field is a small granite peak at Spavinaw, Mayes County, Oklahoma, described below.

Structural reflection of the Nemaha Mountains in the surface strata of shale and limestone of mid-Pennsylvanian age consists of a pronounced interruption of the homoclinal west dip of 20 to 50 feet per mile (½ degree or less) by long asymmetrical anticlinal ridges and domes. These structures have little topographic manifestation, but they show east (reverse) dips of as much as 120 to 200 feet and this reversal frequently extends over a distance of one or two miles.[11] West (normal) dips are steepened by the folding. The exact superposition of these structures over granite hills cannot be determined because too few wells are ever drilled in one locality, but a majority of the wells which found the high points in the granite were located on surface structure. Besides the accordance of steep east dip and steep east flank of the Mountains, there is an exceptionally steep north dip in Pawnee County, Nebraska, at the north end of the known Mountains.

The oil-bearing sands west of the ridge and the deeper barren sands east of the ridge, both of which are correlated with the Tyner formation, dip at but slightly greater angles than the Pennsylvanian strata. Therefore, pre-Pennsylvanian folding is no more intense here than elsewhere in Oklahoma and Kansas. But, the Mississippian formations, according to Aurin, Clark and Trager,[12] do not extend north of the Eldorado field on the west side of the Mountains.

The entire area of the present State of Kansas must have suffered some post-Ordovician, pre-Mississippian as well as post-Mississippian, pre-Pennsylvanian erosion. But, the only movement which affected the Nemaha region exclusively appears to have been differential uplift (faulting?), which may have prevented Mississippian deposition or have caused pre-Pennsylvanian erosion over part of the Mountains.

[11] See Cottonwood Falls folio, U. S. Geol. Surv., no. 109, 1904 and structure contour map of same area (size 5½ x 7 inches) printed by the Geological Survey of Kansas. Contrast with Leavenworth-Smithville folio, U. S. Geol. Surv. no. 206, 1917.

[12] *Op. cit.*

The delineation of the main granite ridge has reduced to a minimum the number of tests along it or below the main producing sand away from it. For this reason the details of structure on either side are little known; the steep east flank, proved in only a few places, is extended the length of the ridge and the west dip, indicated as being very gentle over a broad area, is in reality untested. The Winkler granite well in sec. 2, T. 7 S., R. 5 E., Riley County, 30 miles west of the main ridge, was located on a line of similar surface folding and probably of similar buried hills. Other tests on the line of folding were not drilled deep enough to reach granite. Similarly, the well-known Beaumont line of folding east of the main ridge is believed by some geologists to be another granite ridge, but no granite has yet been reached, unless it is the arkosic sand in the Empire well, sec. 35, T. 27 S., R. 8 E., from 3,470 to 3,855 feet, which is supposed to be the normal depth for the pre-Cambrian granite. The east side of the Beaumont line of folding is abnormally steep and has been considered by some to represent a fault which reaches the surface as a monocline.

Near the Oklahoma state line the granite ridge and Beaumont lines of folding converge. The former continues southward from Eldorado and Augusta past Oxford, the latter through the Newkirk and Ponca City fields. All the structures along these and parallel folds (as Blackwell, Tonkawa-Billings, Garber, and Deer Creek) show remarkably steep surface dips as high as 5 to 10 degrees[13]—in a region of low homoclinal west dips the same as farther north, but with a notable absence of minor structures which are so abundant in Kansas.

Only one well in this area (sec. 18, T. 28 N., R. 3 E.) is reported to have reached pre-Cambrian (at 4,818 feet) but these sharp folds rising abruptly from a structural plain are believed

[13] Structure contour maps of some of these lines of folding are given in "Petroleum and Natural Gas in Oklahoma," Okla. Geol. Surv., Bull. 19, pt. 2, 1917; D. W. Ohern, "Ponca City Oil and Gas Field," Okla. Geol. Surv., Bull. 16, 1912; A. E. Fath, "An Anticlinal Fold near Billings, Noble Co., Okla.," U. S. Geol. Surv. Bull. 641E, 1917.

to overlie hills of pre-Cambrian rock and the Mississippian section may be missing over some of them. The prism of sediments is at least 1,500 feet thicker here than along the main granite ridge and therefore few wells have ever reached a depth at which granite could be expected.

Cushing Field.—The Cushing field, Oklahoma, will ever be famous because it has produced more high-grade oil than any other field ever discovered. The deepest production comes from the Bartlesville and Tucker sands which are unusually close together.[14] A deep test by Cosden & Company in sec. 22, T. 19 N., R. 7 E., on the top of the Shamrock dome, passed almost directly from the Tucker sand into the siliceous limestone of Cambro-Ordovician age and through about 600 feet of it into granite at 3,760 feet. This correlation shows an unconformity between the lower Pennsylvanian and lower Ordovician with an erosion of several hundred feet of sediments. The Cushing field must overlie a local unconformity which probably was also a ridge of pre-Pennsylvanian age because on all sides the stratigraphic section is normal. Moreover, the very important Mounds ("Wilcox") sand is missing. Confirmatory evidence of buried topography is found in the steep dips on the east and west sides of the field and in the abrupt southern termination of the fold and of the line of folding.

Sand Springs, Inola, Spavinaw.—Another granite well was completed in March, 1920, in sec. 22, T. 19 N., R. 11 E., 2 miles south of Sand Springs and 7 miles west of Tulsa. The stratigraphic section at this locality is normal unless there is a thinning of the Cambro-Ordovician siliceous limestone. Therefore, while there is a broad regional bending of the structure contours and of the oil fields in this region there is no reflection of buried topography.

In December, 1921, a buried monadnock of granite was penetrated under an excellent anticline in basal Pennsylvanian strata

[14] Frank Buttram, "The Cushing Oil and Gas Field, Okla.," Okla. Geol. Surv., Bull. 18, 1914; C. H. Beal, "Geologic Structure in the Cushing Oil and Gas Field, Okla.," U. S. Geol. Surv. Bull. 658, 1917.

near Inola, Oklahoma, in sec. 35, T. 20 N., R. 17 E., 30 miles east of Tulsa. The Ordovician section was missing and the granite was struck at 480 feet. About 3 miles farther north granite was struck in 1916 (?) at a depth of about 1,226 feet.

A similar monadnock is exposed at Spavinaw, Oklahoma, in sections 10 and 15, T. 22 N., R. 21 E., Mayes County, on the north side of Spavinaw Creek.[15] The granite outcrops in an area 1,000 feet long and 80 feet wide with sides sloping at angles of 20 to 60 degrees and projects through the Cambro-Ordovician siliceous limestone which was deposited around and over it. The strata on either side and south of the Creek show reflected doming with dips of less than 10 degrees.

Healdton Field.—In 1916 the writer secured a collection of Ordovician fossils which were shot out of an oil well in the Healdton field and which came from a limestone a few feet under the oil sand. Other collections of fossils showed the oil to come from sands of Pennsylvanian age, which rest unconformably on limestones of Ordovician age.[16] The Pennsylvanian fossils are not sufficiently diagnostic to permit the identification of the formation but the Ordovician fossils were identified as representing the lower third of the Simpson formation. At a later date graptolites of the Viola limestone are reported to have been collected in SE. ¼ NE. ¼ sec. 5, T. 4 S., R. 3 W. (Fig. 29).

Subsequent to the collection of Ordovician fossils in Bullhead Oil Co., Daney 14 SE. ¼ NW. ¼ SW. ¼ sec. 4, T. 4 S., R. 3 W., the well was drilled into an oil sand at 2,716 to 2,749 feet and it still produces 12 barrels daily of very high gravity (44° Be.)

[15] N. F. Drake, "Geological Reconnaissance of the Coal Fields of the Indian Territory," Am. Phil. Soc., *Proc.*, vol. 36, pp. 338–42, 1897, described the granite as intrusive into the siliceous limestone and gives a chemical analysis of it. There is every evidence that the granite is a buried monadnock and that the pyrite near it in the chert was deposited by waters circulating through the chert and along the edge of the granite.

[16] Sidney Powers, "The Healdton Oil Field, Okla.," ECON. GEOL., vol. 12, pp. 594–606, 1917; "Age of the Oil in Southern Oklahoma Fields," Am. Inst. Min. Engrs., *Trans.*, vol. 59, pp. 564–75, 1918; J. G. Bartram and Louis Roark, "The Healdton Field, Okla.," Am. Assoc. Petroleum Geologists, Bull., vol. 5, no. 4, pp. 469–474, 1921.

AGRICULTURAL COLLEGE JUN 17 1922 LIBRARY

oil from this Ordovician sand. In January, 1921, the Pure Oil Company, Larney 29, NE. corner SW. ¼ SE. ¼ sec. 4, T. 4 S., R. 3 E., reached the same sand, depth 2,704 to 2,726 feet, and fossils from this well have been identified as Simpson formation. Very heavy oil is also produced from the same formation in a well on Vines dome,[17] near Dougherty in the Arbuckle Mountains, sec. 34, T. 1 S., R. 2 E., depth 1,268 feet, and a show of oil was found in sec. 3, T. 2 S., R. 3 E., at 1,998 feet.

The geological conditions here are different from northern Oklahoma and Kansas because of the proximity of the Arbuckle Mountains. The Hewitt, Healdton and Loco fields and the Wheeler, Graham, Fox, Two-Four and Velma fields are on lines of folding parallel to the Arbuckle Mountains, yet Ordovician strata are known only in the Criner Hills,[18] under the structure on their buried western flank, and in the buried Healdton Hills.[19] There is reason for believing that these are the only Ordovician hills, the first uncovered, the others mantled by a wonderfully productive series of oil sands, and that the other folds have developed between and parallel to these "massifs" or "buttresses" of competent limestone.[20]

[17] Mapped by J. A. Taff, U. S. Geol. Surv., Prof. Paper 31, 1904.

[18] *Idem.*

[19] Named by the writer in ECON. GEOL., vol. 12, p. 596, 1917.

[20] This opinion disagrees with that expressed by R. C. Moore, "Hercynian Orogenic Movements in Southern Oklahoma" (abstract), Geol. Soc. Amer., *Bull.*, vol. 32, p. 48, 1921; "The Relation of Mountain Folding to the Oil and Gas Fields of Southern Oklahoma," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 1, pp. 32–48, 1921; see Sidney Powers, "The Butler Salt Dome, Freestone Co., Texas," *Am. Jour. Sci.*, vol. 49, p. 142 footnote, 1920. The Glenn shows many asphalt beds. Four miles from the outcrop of the Glenn formation Pennsylvanian strata produce oil at depths of 2,100 to 2,700 feet (sec. 7, T. 2 S., R. 2 W.). The writer has always maintained that these beds and those at Healdton are the Glenn formation which is referred to by Moore, McCoy and Waite (personal communication) to the Lower Pennsylvanian (Strawn?). Fossils collected in the Owl Oil Co. Ida Billy 8, sec. 9, T. 3 S., R. 5 W., depth 871 to 880 feet, have been identified by Dr. G. H. Girty and Mr. P. V. Roundy of the U. S. Geol. Surv. (personal letter Feb. 2, 1922) as probably of Cisco age, or post-Glenn. A plant fragment similar to those in the Glenn formation has been found by W. E. Hubbard above the pay sands in a well on the Amster Oil Co. lease, sec. 16, T. 4 S., R. 2 W., in the Hewitt field.

The Pennsylvanian sediments overlying the Ordovician, believed by the writer to belong to the Glenn, and not to the Cisco formation, were evidently deposited over the Healdton Hills with a peak at a depth of only 800 feet below the present erosional surface in SE.¼ sec. 5, T. 4 S., R. 3 W. Most of the limestone was covered by sand washed in from the south from Llanoria (Sabine),[21] but conglomerate is reported in many wells at the unconformity.[22]

Robberson Field.—Robberson is a similar buried hill of Pennsylvanian sediments in sec. 22, T. 1 N., R. 3 W., northwest of the Arbuckle Mountains, with production in Permian sands deposited against the hill. The Permian section thickens rapidly away from the hill. Limestones of Ordovician age may in places underlie the Permian with no intervening Pennsylvanian.

Red River Uplift.—For many years it has been known, but never published, that there is at least one unconformity at Petrolia, Texas, on the Electra-Burkburnett-Petrolia line of folding[23] (Fig. 29).

[21] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Am. Jour. Sci.*, vol. 2, pp. 61–89, 1921, with complete bibliography; A. W. McCoy, "A Short Sketch of the Paleogeography and Historical Geology of the Mid-Continent Oil District and its Importance to Petroleum Geology," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, pp. 541–584, 1921.

[22] J. W. Merritt, "Pennsylvanian Sedimentation Around Healdton Island," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 1, pp. 47–52, 1920; J. G. Bartram and Louis Roark, *loc. cit.*, p. 471 (but the correlation of conglomerate in Roxana Pet. Corp. Keck 13, sec. 5, T. 4 S., R. 3 W., 1,082–1,092, with the Franks conglomerate is very doubtful).

[23] W. E. Wrather referred to this uplift, but not by name, in 1917 (Southwestern (Am.) Assoc. Petroleum Geologists, *Bull.*, vol. 1, p. 125) and Wm. Kennedy has worked it out in detail. More recently L. J. Youngs and C. O. Nickell mapped the unconformities in the Burkburnett field and the former has described them to the writer. Mr. Kennedy and W. E. Hubbard have kindly furnished the writer with well logs and sections. Petrolia is described by E. W. Shaw in U. S. Geol. Surv. Bull. 629, 1916, and in Bull. 716 D, 1920. Petrolia and Electra are described by J A. Udden and D. McN. Phillips, "A reconnaissance report on the geology of the oil and gas fields of Wichita and Clay counties," Univ. Texas, *Bull.* 246, 1912.

The producing sands[24] in Petrolia and Burkburnett but probably not in Electra directly overlie limestone of Ordovician age in the fields, but on the sides of the anticlines a series of lower water-bearing sands appear which do not extend over the highest parts. In some places the producing horizon is missing and a high point in the limestone is found, which fact shows that the sands were deposited around and over these hills but were not derived from them. Post-Permian movements have caused a superposition of structures in the sediments overlying the buried hills—the "Petrolia Hills."

In 1919 the Producers Oil Co. drilled Byers 41 into granite at 4,240 feet, north of Petrolia. The well passed through an incomplete section of Pennsylvanian sediments and entered limestone at a depth of 2,500 feet, which is of Ordovician age from 2,700 to 4,240 feet, or possibly from a shallower depth. Lithologically the limestone series resembles that of Ordovician age in the Arbuckle Mountains.

Mr. Lee Hager[25] has called attention to the existence of these Ordovician limestones at a shallow depth and he correlates all the limestone in the Byers 41 well with the Ordovician. He describes the uplift near the Red River, of which Petrolia, Burkburnett and its associated fields, and Electra are a part, as a Pennsylvanian-Ordovician unconformity. In the absence of satisfactory paleontologic evidence in Petrolia his conclusions are supported by the discovery of Ordovician Arbuckle (Ellenburger) limestone and of pre-Cambrian schist in several wells near Red River, in Clay, Montague and Cooke counties, Texas and Jeffer-

[24] L. C. Glenn, "Some Paleontological Evidence on the Age of the Oil-bearing Horizon at Burkburnett, Texas" (describes Cisco, Middle Pennsylvanian, fossils from Hamilton Oil Assn. well, sec. 13, T. 5 S., R. 15 W., Tillman Co., Okla., depth 1,581 to 1,586 feet), Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, pp. 154–8, 1921; R. C. Moore, *idem*, p. 324; A. W. McCoy, *idem*, vol. 5, p. 568.

[25] Lee Hager, "Red River Uplift has Another Angle," *Oil and Gas Journal*, Oct. 17, 1919, pp. 64–5; P. V. Roundy, in U. S. Geol Surv. Bull. 726 F, p. 293, 1922.

son and Love counties, Oklahoma.[26] Evidently this uplift is a part of Llanoria. The eastern end may join or parallel the Preston anticline in Marshall Co., Oklahoma, and Grayson County, Texas.

Wichita Mountains.—At the close of Permian sedimentation in Oklahoma the Wichita Mountains must have been completely buried by horizontal sediments. Subsequently peak after peak has been uncovered by erosion until at the present time a great part of the ancient mountain range is exposed with its fossil Pennsylvanian-Permian topography scarcely touched by subsequent erosion. The Granite ridge of Kansas is believed to be a similar mountain range, tapering gently to the south as the Wichitas do to the west, with steep dips on either flank and on the individual peaks and with steeper topographic slope on the east as in the Wichitas, on the north. There can be no question but that the Wichitas stood as monadnocks in the Pennsylvanian shallow seas and at the same time the Nemaha Mountains stood in the deeper seas to the north, farther from the shore. The situation is analogous to that between the Healdton and Criner Hills.

East of the Wichita Mountains, Ordovician limestone hills with superimposed Pennsylvanian-Permian folds extend to the north line of T. 1 N., R. 9 W. West of the visible peaks a well in sec. 27, T. 7 N., R. 25 W., located on surface structure, was drilled into a granite at 2,765 feet. The Pierce Oil Corp. well

[26] The following wells have encountered older rocks: Cooke County: Tippitt & Darnall, Ball 1, 5 miles north of Myra, Ordovician limestone, 2,195–2,900 feet (Dr. J. A. Udden); Muenster Oil & Gas Co., Yosten 1, 2½ miles north of Muenster, Ordovician limestone at 2,005 feet, hornblende granite, 2,620 to 2,700 feet (Virgil O. Wood); Benfield, Ball 1, O. F. Leverette Survey, 7½ miles northwest of Gainesville, limestone 1,308 to 2,655 feet. Montague Co: Wright, et al, Monroe 1, 7 miles north of St. Jo, granite at 3,007 feet; well 10 miles northeast of St. Jo, crystalline schist 3,200 feet (Dr. J. A. Udden). Oklahoma: Wilkerson, sec. 18, T. 5 S., R. 8 W., Ordovician limestone reported 2,200 to 2,508 feet; Empire Gas & Fuel Co., Seay 1, sec. 35, T. 6 S., R. 5 W., Arbuckle limestone 3,247 to 3,358 feet; Simms Pet. Co., sec. 14, T. 7 S., R. 6 W., Orthoclase gneissic granite 2,600 to 2,760 feet (C. W. Honess). See H. M. Robinson, "Geologic Structure and Oil and Gas Prospects of a Part of Jefferson Co., Okla.," U. S. Geol. Surv. Bull. 726F, 1922.

nearby in sec. 21, T. 8 N., R. 26 W., found a show of oil at 2,050 feet, about 365 feet above the granite. This well was higher on the structure. Many other wells on the flanks of the Wichitas have penetrated granite or Ordovician limestone[27] while others a few miles away from the mountains pass through Pennsylvanian strata which are everywhere concealed by overlap of the Permian so that they do not outcrop. Pennsylvanian fossils have been found in the Walters and Duncan fields.

Amarillo Hills—Surface structures are concealed by a mantle of Tertiary deposits between the Oklahoma state line and the Canadian River valley west of Canadian. Either the continuation of the Wichitas or granitic spurs from the Ancestral Rocky Mountains[28] have been found beneath the very large folds of the Canadian Valley and every well drilled deep enough on the summits of these enormous structures has found felsite, whereas the deeper tests off structure have found no felsite and, instead, thousands of feet of shale and limestone below the petroliferous

[27] Some of the wells which have penetrated granite or Ordovician limestone are listed: Emerald Oil Co., Callahan 1, sec. 34, T. 4 N., R. 11 W., limestone 850 to 1,086 feet; Short Grass Oil & Gas Co., Perdelwetz 1, sec. 31, T. 4 N., R. 11 W., limestone 1,575 to 3,290 feet; sec. 7, T. 4 N., R. 11 W., limestone 2,345 feet; sec. 31, T. 5 N., R. 11 W., limestone at 1,974 feet; sec. 33, T. 3 N., R. 20 W., limestone at 1,555 feet; sec. 36, T. 1 N., R. 15 W., limestone 1,200 feet; Walbert in sec. 14, T. 1 N., R. 13 W., Viola limestone 1,000 to 1,340 feet; sec. 9, T. 1 S., R. 12 W., limestone at 1,439 feet; Amjlett and Malone, Pe-we-ti-pe 2, sec. 11, T. 2 N., R. 14 W., limestone 215 to 1,947 feet; Grandfield Oil & Gas Co., sec. 9, T. 4 S., R. 15 W., limestone 2,220 to 2,470 feet; Comanche Pet. Co., Clara Wilson 4, sec. 19, T. 2 S., R. 7 W., limestone 3,378 to 3,636 feet; Minnehoma Oil Co., sec. 34, T. 2 S., R. 6 W., limestone reported 2,360 to 2,612 feet. Between Fort Sill and Duncan field Arbuckle limestone is reached at a shallow depth, ranging from 440 feet in sec. 21, T. 2 N., R. 11 W., to from 1,606 to 2,505 feet in the Sykes-McAlester well, sec. 5, T. 1 N., R. 9 W., and 2,000 feet in sec. 20, T. 1 N., R. 10 W. This limestone carries sulphur water. This list of wells was furnished by Mr. R. A. Birk.

[28] W. T. Lee, "Concerning Granite in Wells in Eastern New Mexico," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, pp. 163–7, 1921; Sidney Powers, "The Solitario Uplift, Presidio-Brewster Counties, Texas," Geol. Soc. Amer., *Bull.*, vol. 32, 1921; R. T. Chamberlin, "The Building of the Colorado Rockies," Jour. Geol., vol. 27, p. 150, 1919.

horizon. The Masterson (John Ray) dome north of Amarillo yields gas in a dolomitic limestone of Permian age at depths of 1,600 to 2,200 feet directly over felsite and some of the gas comes from the weathered surface or arkosic residue of the red felsite.[29] The south flank of the structure is 8 miles long, the north flank is probably a regional dip, the east and west flanks are about 14 miles long with 450 feet of closure (Fig. 29).

The B. S. Burnett (6666 Ranch) dome north of Panhandle has yielded gas at depths of 2,300 to 2,800 feet on top of the felsite, which here is at a depth of about 2,800 feet on the summit of the dome, and oil in a lower horizon at 3,045 feet on the flanks. The diameter of the dome is about 15 miles. Elsewhere the Triassic and Permian sediments of the Panhandle dip southeastward at a rate of 5 to 15 feet to the mile. Between the Red River and the northern end of the Panhandle no structures are known other than these domes over buried granite hills. Farther west in Oldham County the horizons which produce oil and gas do not cover the buried felsite hills.

New Mexico Examples.—Near Anton Chico, New Mexico, 110 miles from the Texas state line, the Gypsy Oil Co. drilled into granite on the summit of a very large dome in sec. 30, T. 11 N., R. 19 E., at 2,000 feet. This peak may be one of the connecting links between the Appalachian folding and the Ancestral Rocky Mountain folding. Another granite peak was found by the Continental Oil Co. on the Baker Ranch in sec. 6, T. 31 N., R. 33 E., in the northeastern corner of New Mexico, on the

[29] C. N. Gould, "The Geology and Water Resources of the Western Portion of the Panhandle of Texas," U. S. Geol. Surv. Water Supply Paper 191, 1907; "Preliminary Notes on the Geology and Structure of the Amarillo Region," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 3, pp. 269–75, 1920; Ranch Creek Oil Co., Masterson 1, encountered a rock from 2,350 (?) to 2,370 feet, described as a felsite with muscovite phenocrysts and microfelsitic groundmass. Amarillo Oil & Gas Co., Masterson 1, 3, and 5 and Bivens 1 stopped in felsite. Emerald Oil Co., Masterson 1, had felsite or arkose 2,010 to 2,045, then gas, and felsite at 2,249 feet. On the Bravo dome in Oldham County, Humble Oil & Ref. Co., Shelton 1, entered felsite at 2,560 feet; Benedum & Trees, Matador 2, felsite at 2,380 feet; Shelton 1, felsite at 2,460 feet.

Cimarron River, at a depth of 2,725 feet.[30] On the eastern side of the Sacramento Mountains granite was encountered unexpectedly by the National Exploration Co. at a depth of 2,000 feet in sec. 21, T. 11 S., R. 18 E., on the Picacho anticline near Tinnie, west of Roswell. The Buchanan well of the same company in sec. 25, T. 2 N., R. 20 E., entered granitic sand at 2,560 feet.

Tamasopo Ridge.—The principal oil fields of Mexico are confined to a narrow zone over 90 miles long which has been explored from Dos Bocas on the north past the Tuxpan River on the south. Gusher production is obtained from the top of the Tamasopo Lower Cretaceous limestone with the oil and associated water under enormous hydrostatic pressure. The limestone outcrops on the western edge of the Tampico embayment, but it is scarcely known in deep wells between the outcrop and the oil fields, which are along the eastern margin of the embayment. It suddenly appears beneath the oil fields at a depth of only 2,000 feet. Farther eastward it dips rather steeply toward the Gulf of Mexico.

A buried ridge theory may be advanced to account for the abrupt termination of the limestone on the western edge of production. The great discrepancy in depth between producing wells and offside dry holes indicates either a fault or a buried escarpment. Also, the vast thickness of shales west of the ridge is not present over it. A common conception of the paleogeography is that this ridge was exposed to aërial erosion and that the cavernosity of the limestone was caused by ground water solution.

[30] J. K. Knox, "Geology of New Mexico an Index to Probable Oil Resources," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 1, p. 100, 1920. Arthur Eaton (Discussion), Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, p. 331, 1921; J. L. Rich ("A Probable Buried Mountain Range of Early Permian Age East of the Present Rocky Mountains in New Mexico and Colorado," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 5, pp. 605–608, 1921) refers these granite knobs to an extension of the Paderna! Hills from the mountains by that name into Colorado.

ORIGIN.

Type of Folding.—Little attention has been paid to the effect of buried topography on the structure of overlying sediments; in fact, structural geology before the era of petroleum investigations scarcely considered the flat-lying sediments. It has always been difficult to ascertain the topography of an ancient erosional surface and it is difficult even at the present time to present proof regarding buried topography except in such examples as the Wichita Mountains.

Folding of the type found in the Mid-Continent field is so gentle and extends so far from the apparent source that it becomes difficult to account for by the theory of tangential compression alone. The intensity of folding does not vary directly with the distance from the old shore line, but is related to depth in the prism of sediments. Structures in the older Paleozoic strata on the edge of the Ozark uplift in eastern Oklahoma resemble those in strata of the same age still buried beneath the Pennsylvanian in the deeper oil fields.

From the outcrop of the basal Pennsylvanian to the Permian contact in Oklahoma and Kansas the surface folds are largely noses and terraces. The anticlines of Kansas are arranged in linear manner and have closures of 5 to 30 feet. The numerous and irregularly distributed domes and anticlines in Osage County, Oklahoma, averaging less than one mile in enclosed area,[31] have closures of from 10 to 180 feet. South of Osage County the west dip steepens and for 40 miles few closed surface structures are known. In the Okmulgee district the northernmost closed surface structure is at Schulter.

In north-central Texas between the Electra field and the Llano-Burnet (Central Mineral) Region very few closed surface folds are known in the Pennsylvanian in the area producing oil. The higher Pennsylvanian strata unconformably overlie the Bend formation of uppermost Mississippian and lowest Pennsylvanian

[31] C. V. Millikan, "Inter-relations of the Folds of Osage County, Oklahoma," Am. Assoc. Petroleum Geologists, Bull. 4, no. 2, pp. 151–8, 1920.

age and the regional dips of the two formations are different. Hence, surface, terraces and noses overlie closed anticlines in the Bend.[32]

Paleozoic unconformities are known between the Ordovician and Mississippian, above the Mississippian (post-Bend, pre-Strawn in Texas), in and at the close of the Pennsylvanian and above the Permian. In the Nemaha Mountains the Mississippian and Ordovician strata abut the east side of the ridge, but the former are thought to be missing north of Eldorado on the west side. The "Oswego"-Big Lime series is the lowest to cross the ridge near Cottonwood Falls (T. 19–20 S., R. 7 E.). Therefore the ridge is probably of pre-Ordovician age periodically rejuvenated. In the Cushing field the Mississippian was probably never deposited over the summit of the Ordovician ridge. In the Healdton field the unconformity is believed to be post-Bend, pre-Strawn or earlier; in the Red River uplift the same with later movements. The Wichita, Amarillo, and New Mexico buried hills are pre-Permian and probably Pennsylvanian.

Hypotheses.—The origin of the Mid-Continent structures may be explained by a number of hypotheses which are more or less interrelated and the several types of structure cannot all be explained by one hypothesis. The hypotheses are: (1) tangential compression, (2) rock flowage, (3) warping during deposition, (4) torsional faulting, and (5) condensation of sediments. These will be discussed in order.

1. Tangential compression is the accepted theory of the origin of folds, but the objections raised to it are that the folds in question are far from the source of the compressive forces and that they are everywhere of uniform size except that the largest structures seem to be invariably superimposed over buried hills. If these hills have acted as buttresses, some of the objections are overcome.

[32] W. E. Pratt, "Geologic Structure and Producing Areas in North-Central Texas Petroleum Fields," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 3, pp. 44–70, 1919; F. B. Plummer and R. C. Moore, "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," Univ. Texas Bull. 2132, 1922.

The folds are distinctly not of the Appalachian type, nor are they altogether analogous to the Colorodoan type. The prism of sediments is thin and faulting is present. Partial accordance of the arrangement of flexures with the regional bending of the sediments around the western edge of the Ozarks is noticeable. Further, it is possible to connect many of the flexures with straight, intersecting lines corresponding to Hobbs' "earth lineaments,"[33] called by Harris "lines of fracture"[34] and by McCoy "lines of stress,"[35] but such lines do not explain the folding. Pressure can be transmitted in direct proportion to the competence of the medium of transmission. McCoy[36] has argued that the crushing strength of limestone would be exceeded by thrust from the Ozarks sufficient to produce the small folds in Oklahoma and Kansas. However, the main thrust is transmitted through pre-Cambrian rocks and the amount of shortening across the geosynclinal prism must be measured in terms of the warping and compression in these rocks. The blanket of overlying sediments, partially consolidated and less competent, acquires its structure from the movements which take place in the older rocks, rather than from forces transmitted tangentially through this blanket independent of the older rocks. And the character of folding in the older rocks depends on their lithology and preëxisting structure—hence, positive elements occasionally stand out in the older terrane.

2. In order to account for the widespread unarranged flexures Gardner[37] advanced the hypotheses of folding by vertical thrust caused by deep-seated rock flowage. Such a form of isostatic

[33] W. H. Hobbs, "Lineaments of the Atlantic Border Region," Geol. Soc. Amer. Bull., vol. 15, pp. 483–506, 1904.

[34] G. D. Harris, "Oil and Gas in Louisiana," U. S. Geol. Surv. Bull. 429, p. 9, 1910.

[35] A. W. McCoy, Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 5, p. 579, 1921.

[36] A. W. McCoy (Discussion), Southwestern (Am.) Assoc. Petroleum Geologists, *Bull.*, vol. 1, p. 109, 1917.

[37] J. H. Gardner, "The Vertical Component in Local Folding," *idem*, pp. 107–09.

compensation is generally applied to areas of continental size and his application to folds which encompass less than one square mile is debatable. The adjustment which followed Permian sedimentation would produce lateral crowding of which the Mid-Continent folds may be an example.

3. Warping of sediments accompanied by faulting during deposition has been advanced by McCoy[38] as a hypothesis to explain the accumulation of petroleum. Professor Schuchert[39] suggests that the Mid-Continent structures were "made during the times of warping that made for or against the epeiric seas. Therefore an old land surface might develop local ridges due to the warpings that bring in the seas. These local ridges appear to be conditioned by the previous structure, therefore the similar alignment of all seaways."

Paleogeographic conditions have been too long neglected. It has recently been found that a number of the oil fields in Kansas, as Sallyards,[40] Teeter,[41] Fox-Bush and many of the shallow fields, are thick sand lenses and that the structure mapped on the top of the sand is the same as an isopacheous map of the sand lens. The sand lens is usually crossed by a fold but it produces oil beyond the edges of this fold. Aside from these local conditions such uniform stratigraphy has been proved to exist over broad areas that most individual small structures cannot have been caused by contemporaneous warping as postulated by Professor Schuchert, irrespective of the origin of the warping. Larger features, such as the larger buried ridges and their sedimentary cover, were undoubtedly affected by such movements.

4. Torsional faulting, along lines of weakness, has been

[38] A. W. McCoy, "Notes on Principles of Oil Accumulation," *Jour. Geol.*, vol. 27, pp. 252–62, 1919; Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 5, p. 571, 1921.

[39] Letter to the writer, Dec. 1, 1921.

[40] W. R. Berger, "The Relation between the Structure and Production in the Sallyards Field, Kansas," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 5, no. 2, pp. 276–81, 1921.

[41] Everett Carpenter, manuscript in preparation, to appear in Econ. Geol., vol. 17, 1922.

thought by Robert H. Wood and later published by Fath[42] to explain the belt of en echelon faults which crosses northern Oklahoma and southern Kansas. Fath has applied the same hypothesis to the origin of the "Granite ridge" and of anticlinal folds. He believes that the faults or zones of weakness existed in the basement terrane in pre-Cambrian time and that later displacements and readjustments broke the overlying sediments, many of the breaks not reaching the present surface. In support of this hypothesis he points to the asymmetrical form of many anticlines and to the increase in degree of folding with depth. But, what few faults have been proved by well logs to exist below and not at the surface have very slight displacement and are subordinate to and not the cause of the folding.

5. Condensation of sediments around and over buried hills has been thought by many geologists, ever since the recognition of the first granite in Kansas, to have been an important factor in the formation of closed folds. The first adequate discussion of the question was by Professor Blackwelder,[43] who showed that in a stratigraphic section such as exists at Eldorado, Kansas, a condensation during lithifaction of 35 per cent. is possible, or, in other words, a buried hill 700 feet high could produce an anticline with 160 feet of closure 2,700 feet above the top of the hill. Mehl[44] previously endeavored to explain all ordinary closed structures in the Pennsylvanian by the same process, but this explanation is possible only if there is something to cause relative condensation. Uneven condensation over buried hills is a most important factor in the formation of superimposed folds as clearly shown in studies of well logs. There is often marked vertical convergence of beds along lines radial to the buried hills, especially in shales where the folding is gentle.

[42] U. S. Geol. Surv., Prof. Paper 128 C, 1920; McCoy, *loc. cit.*, p. 577.

[43] Eliot Blackwelder, "The Origin of the Central Kansas Oil Domes," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 1, pp. 89–94, 1920; W. B. Wilson, "The Origin of Clay Slips," ECON. GEOL., vol. 11, p. 385, 1916.

[44] *Idem*, p. 92 footnote (manuscript not published to knowledge of writer and not seen by him).

Field evidence and analogy from such evidence proves the existence of buried hills. Among examples cited the Spavinaw and Inola hills and probably the Nemaha Mountains date from the pre-Cambrian, the others from the upper Paleozoic. Warping which initiated and closed the incursion of successive epicontinental seas affected the larger buried hills in a positive manner and condensation of sediments accentuated the buried topography in overlying strata. Relatively slight tangential compression accompanying readjustment in the Ozark element and in Llanoria was reflected through and from the basement pre-Cambrian rocks and caused the development of flexures in northern Oklahoma and Kansas and in west-central Texas. All these movements in the sediments diminished in intensity upward rather than laterally.

Buried ridges, such as the Nemaha Mountains and Red River uplift, acted as barriers to such movements in upper sediments. In Oklahoma and Kansas north of a line between the Cushing fields and Ozark uplift closed surface structures with lack of parallelism are general. South of this line and north of the Ouachita folding they are absent. The buried hills at Cushing and in the Nemaha Mountains caused the younger sediments of the intervening area to be compressed in a limited space while the same forces acting farther south were dissipated over a broader area with a certain amount of gliding in the higher part of the section, thus giving rise to closed folds below and flexures above. Furthermore, if the buried hills acted as buttresses, the folding should be the steeper on the side from which the forces acted and this is the case in the Nemaha Mountains.

The problem of determining the presence or absence of buried hills in advance of drilling may be attacked from a study of the nature and extent of the folding and of the paleogeographic and orogenic history of the region. Aside from such geological study two possible physical methods have been suggested, but unfortunately not yet tried. Variation in intensity of gravity is one method, as has been pointed out by the writer,[45] but little is known

[45] *Am. Jour. Sci.* (4), vol. 44, p. 149, 1917.

of the anomalies of gravity. The second method is sound ranging, a process of initiating earth waves at the surface and recording their impact against a distinctive subsurface plane of demarcation between strata of different hardness and elasticity.[46] This method is now being experimented with to distinguish formations at shallow depths.

IMPORTANCE TO PETROLEUM ACCUMULATION.

Petroleum accumulates in structural reservoirs which are usually located in regional synclinoria. In regions of extremely gentle folding such as the Mid-Continent, the major structures are found to have some special cause for existence, usually they overlie buried hills, and it is these structures in which petroleum accumulation is at a maximum or else entirely lacking.

Buried hills may themselves serve as reservoirs and contain petroleum as the Ordovician oil in the Healdton field and the vast accumulation in the Tamasopo ridge, or the upturned strata in them may have supplied oil to accumulate in overlying beds. It is theoretically possible for strata flanking buried hills to yield oil into a reservoir in the buried hill proper, where the hill protrudes through petroliferous strata and is porous. Such an explanation has been suggested for the Tamasopo production in Mexico.

Petroleum-bearing horizons in the surrounding strata may or may not extend across the summits of the buried hills. The petroliferous Cherokee shale and the older Paleozoic petroliferous sands and cherts which submerged the flanks of the Nemaha Mountains do not span the ridge north of the Eldorado field. Up to the present time exploration has not revealed the presence of oil in these sands and cherts along the contact with the granite. At Eldorado and south of Eldorado the oil has accumulated over the more deeply buried hills. North of Eldorado it has accumulated on minor flexures west of and parallel to the Mountains.

[46] J. A. Udden, "Suggestions of a New Method of Making Underground Observations," Am. Assoc. Petroleum Geologists, *Bull.*, vol. 4, no. 1, pp. 83–5, 1920.

East of the ridge and in the syncline production has not been found probably because of a limited area of accumulation and absence of sand.

Deeper sands often fail to cover buried hills, as is the case at Cushing, Healdton, Red River and Amarillo. At Amarillo the oil sand in the Burnett dome underlies the gas horizon and was never deposited over the top of the dome. If this and the Masterson dome had stood a little higher in the Permian seas the gas horizon would not have covered either of them. Therefore, in areas of gentle folding the flanks and not the summits of the largest structures offer the most favorable location for deep tests. Further, dry holes which encounter an unconformity on the top of such a structure do not condemn the flanks. The flank which presents the greater area for accumulation is the most favorable in such cases.

The importance of production obtained in reflected buried hills is very evident from statistics. The total production of Kansas including 1921 was approximately 227,000,000 barrels of which nearly half has been produced by Eldorado and Augusta. Cushing has produced 204,000,000 barrels, the fields of Kay, Grant, Garfield and Noble counties 50,000,000 barrels, and Healdton 87,500,000 barrels through 1921 or a total of 79 per cent. of the total production of 1,185,000,000 barrels for Oklahoma through 1921. The Red River fields in Texas have produced through 1921 about 142,000,000 barrels or 45 per cent. of the total north Texas production. In Kansas, Oklahoma and north Texas approximately 34 per cent. of the total production has been on structures superimposed over buried hills.

AMERADA PETROLEUM CORPORATION,
PETROLEUM BUILDING,
TULSA, OKLA.

NEW ASPECTS OF THE GEOLOGY OF THE PRINCIPAL ORE-BEARING PROVINCES OF SIBERIA.

P. P. Goudkoff.

An attempt at a comprehensive and systematic description of Siberia, as a complex and diversely metallogenetic region, has been made only by De Launey.[1] However, when De Launey's studies were made, information on the geology of Siberia was meager and fragmentary and present ideas on metallogenetics were not sufficiently developed. Since then, beginning in 1912, extensive systematic geological investigations have been made in various areas, and great progress has been made in theoretical conceptions as to metallogenetic processes, due mainly to the work of American geologists.

In the light of the new observational and theoretical advance, it is now both possible and necessary to make a new description and classification of the mineral deposits of Siberia, and I therefore venture to undertake this task.

According to present ideas, the properties of every ore deposit are determined: by the nature of the geological process which causes the concentration and deposition of the given mineral substance; by the physico-chemical conditions of this process; by the geological composition and structure of the crust of the earth in the region where the process took place; by the geological processes operating in the same region after the formation of the deposit; and by the order in which the successive processes replaced one another.

For the deposits containing metallic substances which originate in a magma, it is worth while to notice, besides the mentioned factors, one more—the chemical character of the magma.

Since all the conditions under which one or another process

[1] "La Geologie et les Richesse Minerales de l'Asie."

takes place could hardly be the same in different places, even of a small area, the same process may lead to the formation of deposits of very different character, but for each region certain relations must exist between one geological structure and the ore deposits therein.

In this review I hope to illustrate these statements by examples from Siberia. But since the geology of Siberia has not yet been studied exhaustively, I do so only under some limitations. In considering the Siberian ore deposits the following premises may be accepted:

First. The igneous rocks play the first and prinicipal rôle in the formation of the majority of the ore deposits;

Second. The main conditions determining the character of most of the primary ore deposits are the intrusion of the magma from the interior of the earth and the distance from the surface at which the ore matter was deposited;

Third. The variation in the ore deposits in a given region is for the most part due to erosion, by which parts of the crust of the earth, formerly at different depths, are exposed at the surface;

Fourth. The general characteristics of the igneous rocks, their textures, and the features of the contact changes may be used as criteria to estimate the depths of erosion.

THE KIRGHIZ-STEPPES.

The Kirghiz-Steppes is the most western of all the ore-bearing regions of Siberia. (See Fig. 30.) Sediments ranging from the lower Silurian to the Permian are the most important rocks. In the northern part of the Steppes (and also in its southwestern angle), these rocks are mostly red sandstones, conglomerates, slates, and tuffs. In the southern part, limestone is widely distributed.

The igneous rocks are specially developed in the region between Ekibastus, Akmolinsk, Lake Balkhash and Irtish. In the northern part of this region they appear mostly in moderate-sized stocks of granite (changing into granite-porphyry and porphyry),

and large dikes and sheets of more or less basic porphyrites. Southward from Karkalinsk, intrusive porphyry predominates. Contact metamorphism in the invaded rocks appears mostly as marked silicification. Typical contact metamorphism can be seen in only a few places.

The general character of the ore deposits in the Kirghiz-Steppes is closely dependent on the rock types. This correlation is shown first in the fact that the principal ore deposits are found in those districts where igneous rocks are prominent, *i.e.*, in the eastern

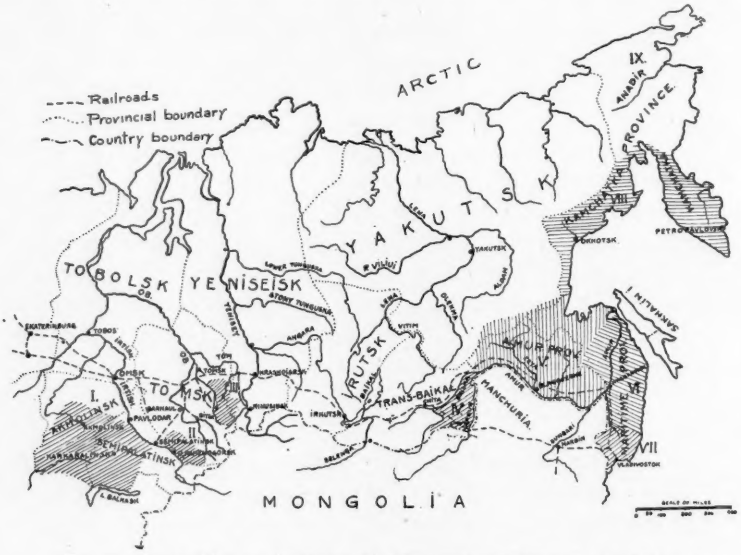

FIG. 30. Index Map of the Principal Ore-Bearing Provinces of Siberia. I. The Kirghiz Steppes; II. Western Altai; III. Kuznetski Alatau; IV. Nerchinsk; V. Left Bank of the Amur River; VI. Sikhota-Alin, northern part; VII. Sikhota-Alin, southern part (South Ussuri); VIII. Okhotsk Kamchatka; IX. Chukotsko-Anadyr.

part of the region, south of the 52d parallel. Further, corresponding to the differences in the character of the rocks, in the northern area, where the rocks are mainly fragmental, intruded by granite

and porphyry, copper deposits predominate; and in the south, a region of limestone and porphyry, the important deposits contain silver and lead.

The character of the mineral deposits is shown also to be definitely related to their positions with respect to the intrusives. Thus, many deposits occurring in porphyry, especially those in the region of Ekibastus, and also between Bayan-Aul and Lake Karasor, are present mainly as thin veins and disseminated copper minerals, oxidized to a depth of 70 to 100 feet.

The deposits adjacent to the granite and granite-porphyry stocks (in the vicinity of Bayan-Aul, and southward from Karkalinsk) are composed mostly of pyrite and chalcopyrite, many carrying galena. They are characterized by a rather high content of gold, in some mines reaching sixty dollars to the ton.

Irregular quartz veins carrying lead and gold, but probably connected genetically with the same granite-porphyry stocks, lie in porphyry and slate at some distance from them.

In the north-south strip of very widely distributed porphyry, traversing central Karkalinsk County, lies a group of deposits consisting of quartz veins and stockworks. Most of them carry several metals (Bish-Cheku, Berkara), but some carry only copper minerals (Neldinskoe, Spask factory).

The deposits in limestone appear as stockworks characterized by predominant lead and small quantities of zinc and copper.

Finally, copper minerals form impregnation deposits in fragmental rocks, mostly Devonian sandstone (northward from Lake Karasor, and in the southwest corner of the region). Thus, nearly every difference in the composition of the rocks in the Kirghiz-Steppes is reflected in the character of the ore deposits.

At the same time, it should be noted that the ore deposits of the Steppes correspond to the geological history of the region to such a degree that the presence of these deposits may be predicted in advance on the basis of that history. Thus, it can be predicted that the Steppes should have deposits of copper, lead and zinc, since those metals are typical of the deposits classed by Lindgren

as formed at intermediate depths, because in the region erosion has uncovered the medial zone. This is proved by the medium size of the granite masses, by the intrusive character of the porphyry, and by the type of metamorphism in the intruded rock.

In the same way, a knowledge of the rock types and history of the southern part of the Steppes predicates the possibility of the occurrence of silver-lead deposits of the Leadville, Colorado, type. In the areas of the basic porphyrites and red Devonian sandstones, we may naturally expect copper deposits of very constant types, such as copper deposits associated with basic lavas, and deposits similar to those of Mansfield.

THE WESTERN ALTAI.

East of the Kirghiz-Steppes is the ore-bearing region of the western Altai. (Fig. 30.) The principal rocks are Devonian sandstones and slates, which in the southern extremity of the range, and in the Irtish valley, give way to slates and dark limestone of lower Carboniferous age.

Here porphyrites and porphyries are the most widely distributed igneous rocks. The porphyries appear in part as flows intercalated with sedimentary rocks and in part as small bodies possibly remnants of old effusions, or intrusive masses, and in any case they are apophyses from granite exposed here and there. The porphyrites appear mostly as dikes.

All the above-mentioned sedimentary rocks are intensely folded, the axes of the folds striking northwest. However, the present relief of the region, according to the investigations of Grenough and of Obrucheff, depends not on the folding but on the faults which cut the region after it was reduced to a peneplain. The faults are, however, nearly parallel to the strike of the sedimentary rocks, and were connected with the uplift of the central part of the range.

The ore deposits of the Altai are located in limestones parallel to the general lines of folding; but the deposits on any different

lines differ in the predominant metal and in gangue minerals. Thus, the middle line passing through the Ridder and Ziryan mines connects deposits distinguished by the predominance of lead and zinc, with barite, the southwestern, or so-called Irtish line, by silver-copper-quartz deposits; and the northeastern by copper with quartz.

Similar relations between metallic composition and the nature of the gangue mineral are found in different parts of the same deposit; thus, the deposits which at the surface carry predominant barite, zinc and lead, have in the lower part predominant quartz and copper. The silver-copper-quartz veins and the copper-quartz veins are apparently only the lower parts of the silver-lead-barite veins from which erosion has removed the upper part.

The general mode of occurrence of the igneous rocks of the Western Altai, their texture and the nature of their metamorphism, all show that in the Western Altai is exposed the zone of deposits classed by Lindgren as formed at intermediate depth under medium pressure, and it would be possible from evidence obtained here to greatly elaborate his classification.

THE KUZNETSKI-ALATAU REGION.

The Kuznetski-Alatau Range forms the watershed between the systems of the tributaries of the Tom and Ob Rivers on the one side, and the Yenissei River on the other.

This range represents a large horst, the central part of which is formed by various metamorphic schists, crystalline limestone (in part, undoubtedly, of Cambrian age), and metamorphosed porphyrites representing the intrusive phase of early voluminous effusions.

Among the rocks lie rather large (5 or more kilometers in diameter) granodiorite batholiths, apparently of early Paleozoic age, as indicated by the occurrence of the pebbles from the batholithic rock locally seen in the Devonian basal conglomerates. The metamorphism of the adjacent rocks is seen in typical hornfelds, *i.e.*, in simple recrystallization of passive rocks without substantial changes in their chemical composition.

The outer zone of the horst, through a width of 15 to 20 kilometers, differs from the interior by the presence in the early metamorphic rocks of many moderate-sized stocks of banatite and pyroxene-syenite. The latter are characterized by great inconsistency of mineralogical composition and texture, changing into granite-porphyry and even quite compact varieties, resembling halleflinta. At the same time, the metamorphism of the surrounding rocks is accompanied by marked changes in their chemical composition, and it would be better, perhaps, to designate the process not as a contact metamorphosis but a *contact metasomatism*.

The ore deposits of the Kuznetski-Alatau Range include gold-bearing quartz veins, iron and copper deposits of the contact-metamorphic type, and copper deposits characterized by the presence of native copper. The gold-bearing veins are closely connected with the granodiorite batholith of the interior of the horst, and cut the granodiorite itself, or the adjacent surrounding rocks. The contact deposits of iron and copper areas are connected with medium-sized stocks of banatite and pyroxene-syenite, and the deposits of native copper are confined to the melaphyre belt which surrounds the horst and, in part, to the adjacent Devonian sandstone in the Minusinsk valley. It can be shown also that these three types of deposits of the Kuznetski-Alatau Range differ with the emanations from which they were derived.

As a result of detailed geological investigation, of prospecting work, and of magnetic surveying in the Telbess iron-bearing region, in southwest part of the Kuznetski-Alatau Range, I came to the conclusion that the deposits of this region may be divided into four types, which differ in their mode of occurrence, their general structure, the distribution of magnetic attraction in accordance with the structure; in the texture of the ore, and in the nature of the predominant gangue minerals.

The origin of such deposits was by emanations radiating from intrusive rocks. These emanations were radiated upward from the intrusive bodies in the form of an inverted truncated cone

CLASSIFICATION OF THE TELBESS IRON ORES.

Mode of Occurrence.	General Structure.	Predominant gangue minerals.	Texture of ore bodies.	Distribution of magnetic attraction.
In the body of the igneous rock	Ore bodies closely associated and surrounded by a narrow belt of metamorphosed rocks	Hedenbergite and andradite	Coarse grained	Several centers of force close together and forming a large nucleus
In the exocontact zone near the igneous rock	Smaller ore bodies farther apart, surrounded by a wider belt of metamorphosed rocks	Andradite	Medium grained	Centers of force well separated
In the exocontact zone somewhat distant	Small lenticular orebodies in large mass of metamorphosed rocks	Iron rich hornblende	Fine grained	Centers farther apart
In the exocontact zone far from the igneous rock	Few thin veins of magnetite in mass of slightly metamorphosed rocks	Epidote	Very compact, resembling cast iron	Centers of force weak, widely and irregularly separated

KANSAS STATE AGRICULTURAL COLLEGE LIBRARY JUN 17 1922

and spread through large bodies of rock. In the course of their progress the emanations deposited the metals carried, and the surrounding rocks gradually absorbed their heat.

As a result of this progress, together with the movement away from the intrusive body, the concentration of the ore matter gradually became reduced, and minerals peculiar to lower temperatures were formed. The detailed study of the mineralogical composition of the deposits shows that the order in which the hedenbergite, andradite, hornblende and epidote replace one another, in the described four types, completely coincides with the succession of the changes in the mineralogical composition of each deposit in the upward direction. Thus, the different types of Telbess deposits are nothing more than different horizons in the rocks which have been mineralized under the influence of the contact metasomatic action of banatite and syenite. And in this we have a new example of the possibilities of the elaboration of Lindgren's classification on the basis of differences in the relation of the physico-chemical conditions to the formation of the deposits.

THE NERCHINSK MINING DISTRICT.

In Eastern Siberia the best known ore-bearing region is the so-called Nerchinsk Mining District, and for two hundred years it has competed with the Altai in its output of silver and lead. It occupies the watershed between the upper tributaries of the Amur-Shilka and Argun, and represents a system of horsts elongated in a northeastern direction and forming the principal watersheds. The horsts are formed from Archæan gneisses, hornblendes and biotite-schists, quartzites and, in part, crystalline limestone intercalated with the same gneisses.

In the slopes of the valleys and secondary watersheds appear two series of the rocks: (1) schists, quartzites and serpentinized limestones; (2) Devonian and lower Carboniferous clay slates, and dolomitized and silicified limestones. The first of these two series is well developed in the northwestern part of the district and especially in its southwestern corner. The second occupies the

southeastern half of the district, where it appears in several more or less parallel and interrupted series. All the rocks described show intense folding with the axes of the folds generally striking northeast, but in some places striking northwest. Younger sedimentary rocks, representing freshwater Mesozoic deposits, appear as small islands mostly laid down evenly.

The igneous rocks are widely distributed and consist of granites accompanied by granite-porphyry facies and metamorphosed rocks of the Paleozoic series. Some porphyries also are undoubtedly present as apophyses of the granites, but there are some sheets of porphyry intercalated in the Paleozoic sediments with which they are faulted. The granites and the porphyries are confined mainly to the slopes of the ranges, while in the lowlands, especially at the eastern boundary of the region, recent rhyolites and trachytes occur through large areas.

Basic igneous rocks are of far less importance, but they do occur in different localities of the region and, as with the acidic rocks, they are eruptives.

From the broader geologic features of the Nerchinsk District, it is possible to foretell something of the nature of the mineral deposits; first, in conformity to the diversity in the igneous rocks a like diversity is to be expected in the mineral deposits; second, the great difference between the geology of the northwestern and and southeastern parts of the region leads to the expectation of contrasting metalliferous deposits; third, in the area over which gneiss is widely spread, deposits typical of those classed by Lindgren as formed at great depth under high pressure and high temperature are to be foreseen. The observed facts coincide with this supposition.

In the northwestern part of the region are found typical deposits of the deep zone, including tin, tungsten, bismuth, molybdenum, and quartz-tourmaline veins. They all reproduce in minute detail the paragenetic characteristics peculiar to this group. They are accompanied by such typically high temperature and high pressure minerals as topaz, beryl (including aquamarine), lepido-

lite, feldspar, tourmaline, etc. These minerals, especially the aquamarine and the tourmaline (black and pink), are recorded in great numbers as distinct deposits.

It is interesting to note that the formation of all of the deposits confined to the region of the gneiss and schist has caused typical metamorphism of the surrounding rocks, but the deposits themselves do not differ from the usual deposits of this type, even in the smoky tint and transparency of the vein quartz.

In the distribution of the deposits a fairly distinct regularity is observable; the more central position is occupied by veins carrying tungsten and bismuth minerals. Veins carrying precious stones and cassiterite form a zone that surrounds the region of tungsten deposits, and quartz-tourmaline veins are found mostly along the periphery of the gneiss, more particularly along its northeastern boundary.

The distribution of the deposits may be explained in the same way as the various types of the Telbess magnetic deposits. Some considerations have led me to think that in the zone in which the high temperature and high pressure deposits were formed, two horizons can be distinguished: a lower, in which tungsten, cassiterite, and topaz are typical; and an upper horizon, in which tourmaline is prevalent.

In the southeastern half of the region silver-lead deposits are widely distributed. Here again they are definitely confined to the Paleozoic rocks, especially to the dolomitized limestones. They occur also along the contacts of the limestones with slates or porphyries, and very rarely, in sandstones.

Most of these deposits are of irregularly lenticular form. The ores are remarkably free from gangue minerals and the limestone in their vicinity shows only strong silicification. Rarely deposits in the form of normal veins of quartz and calcite are found in the sandstone.

The ore minerals in the oxidized portions of the deposits are nearly always the ochres of iron and lead, with cerusite, galena, and zincblende. The galena, zincblende, and pyrite are evidently

the principal sulphide minerals, but they have been reached in only a few of the mines (at depths of 200 to 280 feet). In exceptional deposits lead-iron-manganese ochres are present; and in a few others, arsenopyrite, chalcopyrite, stibnite, wulfenite, and even tellurium minerals are found with the galena and sphalerite.

The genesis of the lead deposits is connected by some investigators with the porphyry; others, pointing to the Paleozoic age of the porphyry, are inclined to consider a granite as the active rock. I believe both sides make a mistake by ignoring the facts that porphyry is only a facies of granite, and that there have been many periods of eruptive activity in the region. It may be that the ore deposition processes also were renewed; and could it not be the cause of the modification in the composition of some of the deposits?

Besides the deposits of precious stones, rare metals, gold, silver and lead, there are in the Nerchinsk District many deposits of iron and copper ores.

For a proper understanding of the metallogenetic province of the Nerchinsk District, these ores are, I believe, of great importance. The data relative to the deposits are not worked out in detail and are so meager as not to permit the formulation of general theories.

THE "FAR EAST" REGION.

The name "Far East" is usually understood to apply to the territory occupied by the Amur, Maritime, Sakhalin and Kamchatka Provinces. The systematic geologic investigation of this territory was begun at a comparatively recent date, and covers, as yet, but a very small area. However, on the basis of the information already gathered, it is possible to say that in the Far East there are at least four more or less distinct ore-bearing areas: Chukhotsko-Anadyr; Okhotsk-Kamchatka; the left bank of the Amur River; and the Sikhota-Alin Mountains, in which, in its turn, we can distinguish a northern and southern (or South-Ussuri) region. (Fig. 30.)

I will confine my discussion to the South-Ussuri region, which

has been better explored than the others, and which in the complicated character of its ore deposits is most interesting and offers the best illustration of my ideas.

On the geological map, the Sikhota-Alin range is shown as a belt of schists and metamorphic sandstones, interbedded with gneisses and gneissoid-granites. This belt gradually narrows in passing southward, and in the southern end of the range can be seen only as occasional small islands rising among the unaltered sediments of Carboniferous, Triassic, and Jurassic age, and some igneous rocks including granites, porphyries and basalts.

Two types of granites are distinguishable. One, of comparatively uniform, medium-grained texture, evidently without porphyritic connections, forms masses that have induced only slight recrystallization in adjacent rocks. The other, of various texture, in some places of granite-porphyry type, has produced contact-metamorphism of metasomatic character, and is nearly everywhere accompanied by porphyry of somewhat later age.

The information respecting the ore-bearing deposits of the south Ussuri region permits the determination of the following relations between the ore deposits and the geologic structure.

Among the metamorphic rocks, pyrite deposits with a large percentage of copper, evidently closely resembling the copper-bearing pyrite deposits of Kishtym in the Urals, are present.

In the outer parts of the granite masses of the type first mentioned are found quartz-molybdenite and quartz-gold-bearing veins, carrying pyrite, chalcopyrite, galena, and zincblende.

With the granites of the other type are associated deposits of magnetite, which, in their complexity and in the magnetite itself, greatly resemble the contact-metasomatic deposits of the Telbess district.

Also with the same granites of the second type, and especially the porphyries that accompany them, are associated many deposits of lead, zinc, and, locally, copper. They evidently are produced in the later phases of the same process, to which the formation of the magnetite deposits is due, because, on one hand, they are con-

nected with the latter by a gradual transition and, on the other, they occur in the outer edge of the porphyry and not as metasomatic deposits in the adjacent limestone.

There are many other ore-bearing districts of the Far East, but I will refer only to the Okhotsk-Kamchatka district, where, some years ago, in the acidic effusive rocks of recent origin, several gold-bearing veins were discovered.

These veins, with high percentage of silver, and with much cryptocrystalline silica, as a gangue mineral, greatly resemble the deposits widely distributed in regions of recently extinct volcanism—deposits classified by Lindgren as having been formed at shallow depths.

SUMMARY.

In general, the character of ore genesis and the nature of the various deposits have such a clear dependence on the geologic history of a given region that from a detailed map of the ore deposits a general idea of this region may be had, and vice versa. I believe also that through the further study of Siberian ore deposits and through experimental investigations it will be possible to determine with such precision the conditions under which ore deposits are formed that the minerals of the deposits will probably furnish as definite a means for classification of the deposits as do fossils for the age of the sedimentary rocks.

The deposits of Siberia not only confirm Lindgren's classification, but give a foundation on which his classification may be considerably elaborated.

Finally, I would like to point out the fact that Asia is the greatest and structurally the most complicated of all continents, and I think that if geological hypotheses can be proven on the geology of Asia they can be accepted as applicable everywhere.

European theories of ore deposits have not been successfully applied to Asiatic ore deposits. I hope that American theories will prove more acceptable. We Russian geologists will be glad to offer any assistance that we can give from our personal familiarity with this greatest continent.

CARE OF RUSSIAN EMBASSY,
WASHINGTON, D. C.

SOME PRELIMINARY EXPERIMENTS ON THE MIGRATION OF OIL UP LOW-ANGLE DIPS.[1]

HAROLD V. DODD.

INTRODUCTION.

The early proponents of the anticlinal theory of oil accumulation advanced the idea that the differences in the specific gravities of water, oil, and gas caused the oil and gas to concentrate at the top of anticlines, and this explanation was accepted without detailed investigation.

The ability of specific gravity differences to cause the segregation after the oil and gas have been delivered to the anticlines has never been seriously questioned, but as it became known that petroleum commonly originated in shales in the form of minute, disseminated droplets, it appeared probable that some other agency than buoyancy caused lateral migration. This conclusion is emphasized by the fact that many of the major pools have accumulated in anticlines whose legs have dips of one degree or less.

Munn[2] especially questioned the sufficiency of buoyancy as a force causing migration. He formulated the hydraulic theory of migration, but never made any experimental attempts to demonstrate it. His idea was that the oil, in the form of an

[1] The experimental work described in this paper was carried on during the spring of 1921. My absence from Stanford University during the summer and fall quarters has delayed the publication of Mr. Dodd's work, as he wished me to review the manuscript before publication. The present article, therefore, was written before the appearance of the interesting contribution of John L. Rich, entitled "Moving Underground Water as a Primary Cause of the Migration and Accumulation of Oil and Gas," in this journal, vol. XVI., pp. 347–379 (1921). Mr. Dodd's work furnishes an experimental and theoretical basis for the conclusions which appear in the above cited article. C. F. TOLMAN, JR.

[2] Munn, Malcolm J. ECON. GEOL., vol. 4, 1909, pp. 141–157; pp. 509–529.

emulsion in water, was carried through the rock pores by moving water; that this moving water, in some cases, because of its greater capillary pressure would accumulate and push ahead of it a considerable portion of the oil and gas contained in the beds, forcing it into the coarser portions of the sands where capillarity is not so great; that some pools were formed by capillarity alone, others by hydraulic pressure, and still others by a combination of the two.

Later McCoy[3] followed up the differential capillarity idea by means of experiments, and concluded that capillarity was the major force active in oil accumulation. The more recent experiments of Mill,[4] and those that are to be described in this paper, however, seem to indicate that differential capillarity is of little or no importance in the major accumulations.

Moving gas has also been considered a probable agent in the movement of oil, but no experiments seem to have been made which would throw much light on accumulation by this process. Thiel[5] made a start along this line, but the conditions established in his experiments could hardly be expected to occur in nature.

The experiments described in this paper were performed for the purpose of investigating the conditions under which disseminated oil will migrate through the sands up low dips. The apparatus used was crude, and no attempt was made to approach the precision of the elaborate experiments of Mills. The latter, however, dealt almost entirely with nearly vertical movements of large bodies of oil, and therefore do not give the information desired.

In the experiments to follow, water or gas, or both, were forced through various combinations of oil and water-sands packed in a glass tube. It was found that by forcing water and a small amount of gas through the sands at the same time, oil could be made to migrate rapidly up very low dips.

[3] McCoy, A. W. *Jour. Geol.*, vol. 24, 1916, p. 798; vol. 27, 1919, No. 4, p. 829.

[4] Mills, R. Van A. Econ. Geol., vol. 15, 1920, p. 398; vol. 16, 1921, p. 124

[5] Thiel, George A. *Eng. and Min. Jour.*, April 19, 1920.

THE MATERIALS AND APPARATUS.

The oil used was from Well No. 2, Bankline, Section 6, General Petroleum Corp., Taft, Calif., and was of asphaltic base.

The gravity of this oil was originally 22 degrees Baumé but it was raised to 30 degrees Baumé by the addition of a mixture of equal parts of gasoline and coal oil.

The water used throughout the experiments was brine of 1.1 specific gravity.

Two sands of medium roundness of grain and 35 per cent. porosity were used. The difference in texture in the two sands is shown in the following screen analyses, in which samples of 1,000 grams were used.

Mesh of Screens.		Max. Size of Grains Mm.	Sand No. 1.		Sand No. 2.	
Through.	On.		Weight (Grams).	Per Cent.	Weight (Grams).	Per Cent.
10	20	1.65	7	.7	509	50.9
20	40	0.83	494	49.4	485	48.6
40	60	0.34	425	42.5	9	.9
60	80	0.21	69	6.9	.....	.....
80	100	0.18	6	.6	.....	.....
100	.....	0.15	.....	.....	.....	.....
				100.1		100.4

The oil-sand was prepared by thoroughly saturating a quantity of sand No. 1 with oil and then hanging it in a cheese-cloth bag to drain. This was done three days before the experiments were started and resulted in a sand of practically constant oil content; only the amount held in place by capillarity was retained.

The water-sands were made up of sand No. 1, or sand No. 2, or both as desired. They were saturated with brine before being placed in the apparatus.

The apparatus consisted of a 7/8-inch (inside) by 30-inch glass tube, into which the sands were packed, and such other devices as were necessary to force water and air through the sands. It was found that the air pressure often had a tendency to loosen

the sand and heave it up the tube, therefore the end of the sand column was capped by a plug of brass wire screen. The ends of the glass tube were closed with rubber stoppers held securely in place with tire tape. There were holes in the stoppers for the admission and escape of water and air.

Air or gas, when used, was forced into the tube through a capillary opening by means of a compressor. Water pressure was obtained either by means of an elevated vessel, or by means of air pressure upon the water surface in a sealed bottle, which had a discharge tube extending to its bottom.

The general arrangement of the apparatus when connected with the pressure bottle is shown in Fig. 31.

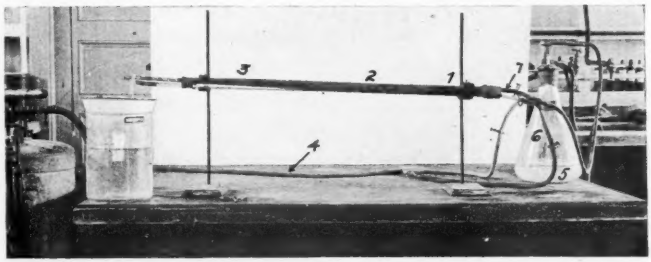

FIG. 31. Apparatus used for experiments. 1. Oil-sand. 2. Water-sand. 3. Water. 4. Air under pressure. 5. Water under pressure. 6. Air under pressure. 7. Water under pressure.

THE EXPERIMENTS.

Experiment 1.—Object: To determine the extent to which oil will migrate through water-sand when buoyancy alone is the propelling force; and also when moving air is the propelling force, the water being under static conditions. Loading: 6 inches of oil-sand at the bottom; then 12 inches of water-sand No. 2 (coarse); the remainder of the tube was filled with water.

The loaded tube was inclined at an angle of 10 degrees with the horizontal, and allowed to stand thus for 24 hours to see if buoyancy or differential capillarity would cause movement of the oil. There was no movement.

Air was then forced through for 1 hour, which resulted in forcing a considerable amount of oil, in the form of globules, 3½ inches into the water-sand. Most of this movement took place during the first 30 minutes. After the air had cleared enough pores to permit of its free passage, there were no further oil movements. In the water-sand the oil stayed in the form of globules and did not wet the sand surfaces.

When the air was turned into the tube the bulk of the water was displaced from the pores of the water-sand, and thus the contact of an excess of water with the oil was lost. As the latter condition was deemed essential to the effective operation of the air as a carrier, it was considered probable that less air, more finely divided, would be more successful. This consideration led to the introduction of the air through capillary openings in all subsequent experiments.

Experiment 2.—Object: To see if moving gas will cause the migration of oil when water conditions are static. (*a*) This experiment was the same as No. 1, except that the air was forced into the sands through a capillary opening, and the amount thus greatly reduced. Even in this case the water was largely removed from the pores by air. Oil moved less than an inch into the water-sand. (*b*) Loading: 6 inches of water-sand No. 2; 3 inches of oil-sand; then 9 inches of water-sand No. 2; the remainder of the tube was filled with water. The object of this loading was to see if placing water-sand below, as well as above, the source of the oil would produce different results.

The angle of inclination was 10 degrees. Air was forced into the bottom of the tube through the same capillary used in (*a*). The air did not bubble through the water in the lower water-sand, but displaced it from the pores and forced it up the tube, thus producing a temporary water current through the sands above. This water current forced the oil from the pores of the oil-sand into the lower portion of the upper water-sand for a distance of 1¾ inches during the first 1½ minutes. By this time the air had taken possession of most of the pores, and subse-

quent oil movement was very slight and slow. In two hours oil had moved 3¼ inches into the upper water-sand, and, as there had been no movement for some time, the experiment was discontinued.

No air moved through the sands until it had almost complete possession of the pores, though of course the actual sand-grain surfaces remained wet. We are forced to the conclusion that when there is no propelling water current, gas will not move through water-sand unless it (the gas) is present in sufficient quantity to displace the water and move in a continuous stream. In other words, buoyancy alone is too weak a force to cause gas movement in water-sands. This is due to the fact that the capillarity of the water prevents gas bubbles from passing through the interstices between pores. The word interstices is used in this paper for the small narrow openings connecting the pores between the grains. Gas bubbles also appear to adhere to the moistened sand surfaces more than oil globules do.

In view of the above, and since, to act as a carrier of oil, gas must be in the form of small bubbles suspended in an excess of water, we are forced to the conclusion that pronounced gas-transportation of oil cannot be expected under static water conditions.

Experiment 3.—Object: To determine the extent to which oil will migrate through dry sand under the propulsion of air. Loading: 6 inches of oil-sand at the bottom; then 12 inches of sand No. 2, *dry*.

The loaded tube was inclined at an angle of 10 degrees with the horizontal, and the air forced into the sands through a capillary opening at the bottom for 1 hour. At the end of this time oil had been driven 7 inches into the dry sand. Most of this movement of the oil took place during the first 15 minutes. In the upper 3 inches of its penetration the oil occupied progressively less of the upper portion of the cross section of the tube, the oil level forming roughly a level line. In this case capillarity evidently greatly aided the upward movement of the oil. In

this experiment the capillary opening for admitting the air was larger than that used in Experiment No. 2, so the amount of air was greater.

Experiment 4.—Object: To see if buoyancy will cause oil to migrate up low or moderate-angle slopes when the oil is present in bulk. Loading: 18 inches of water-sand No. 2; the remainder of the tube was filled with water.

The tube was inclined at an angle of 1 degree. Oil was then forced into the bottom of the tube in such bulk that it occupied all the pores in the bottom 8 inches of sand. The water was driven from the pores, but retained its possession of the actual sand surfaces. After 16 hours there was no change in the position of the oil.

The inclination of the tube was then increased to 10 degrees, and the tube left in this position for 36 hours. At the end of this period a small amount of oil had moved about an inch up the tube, but the bulk of the oil remained in its original position. The small amount that did move appeared to have followed some pockets of trapped air. The latter probably accumulated just ahead of the oil as the oil was being forced into the sand.

Experiment. 5.—Object: To determine the effect of moving water on the migration of oil in water-sand. Loading: 6 inches of oil-sand at the bottom; then 12 inches of water-sand No. 2; the rest of the tube was filled with water. This loading is identical with that of Experiment No. 1.

The tube was inclined at an angle of 10 degrees, and water forced through at the rate of about 15 c.c. per minute by connecting the bottom with an elevated source of supply (70 inches head). The porosity of the sand being 35 per cent., the velocity of the water current through the pores would be about 4.3 inches per minute if all the pores were open.

At the end of 20 minutes oil had moved the entire length of the water-sand and was accumulating upon the water above. In 1½ hours considerable oil had accumulated upon the water above and the movement had become very slow, so the experiment was discontinued. A large amount of oil appeared to be trapped in

the pores of the water-sand, but none of it appeared to adhere to the sand grains.

STATE AGRICULTURAL COLLEGE JUN 17 1922 LIBRARY

The manner in which the oil travels up the water-sands is interesting. When an experiment is first started the oil moves into the water-sand in the form of a more or less continuous, irregular mass which sends off branches into the adjoining pores by short, rapid jumps. This continuity is soon broken up, however, as the oil progresses up the water-sand, and the movement takes the form of short, rapid jumps from pore to pore, by individual globules. These jumps are spasmodic and appear to be due to the pressure of the water rather than to its velocity. The oil globules adjust themselves to the pore spaces and are therefore of all sizes and shapes, but the actual sand grain surfaces and interstices between pores remain in the possession of the water, which seems to act as a lubricant.

Experiment 6.—Object: To determine the effect of moving water upon the migration of oil when the water-sands are comparatively fine. Loading: 6 inches of oil-sand at the bottom; then 12 inches of water-sand No. 1; the rest of the tube was filled with water.

This experiment was identical with Experiment 5, except that the finer water-sand was used, and the rate of flow of water consequently slower. The 70-inch head of water forced water through the sands in the tube at the rate of approximately 7 c.c. per minute, which means a velocity of about 2 inches per minute in the pores when they are all open—some of them would be more or less effectually plugged with oil.

In 45 minutes oil had moved the entire length of the water-sand and was accumulating upon the water above. At the end of 1½ hours a considerable quantity of oil had accumulated on the water and, though some oil was still in motion, the experiment was discontinued.

The manner of the movement of the oil was very similar to that in Experiment 5, except that the movement by individual globules was less distinct—there seemed to be more of a tendency for a series of oil globules in pores to be connected by threads of oil

in the intervening interstices. This was attributed to the greater contrast in size between pores and connecting interstices when the coarser water-sand was used; the greater the contrast, the greater the effect of capillarity, and therefore the greater the tendency for the oil to be restricted to the pores. In both cases, when the oil had been forced from a pore, the latter was left uncontaminated by oil, showing that the water held its grip upon the actual surfaces of the sand grains even when the pores were occupied by oil.

Experiment 7.—Object: To see if a fine zone in the water-sand above a coarse zone will prevent the migration of oil beyond the latter; to test the effect of the presence of moving air after migration by moving water alone has practically ceased. Loading: 6 inches of oil-sand at the bottom; then 3 inches of water-sand No. 2 (coarse); then 3 inches of water-sand No. 1 (fine); then 6 inches of water-sand No. 2; the rest of the tube was filled with water.

The tube was inclined at an angle of 10 degrees, and the bottom connected with the elevated reservoir. Water was forced to flow through the sands for 14 hours. The rate of flow of the water was approximately 15 c.c. per minute at the start of the experiment, but it gradually increased until it was about 30 c.c. per minute at the end. There is no doubt that this difference in the rate of flow was due to the increasing permeability of the oil-sand to water as the oil was displaced from its pores, as no change was made in the elevation of the water reservoir.

In 26 minutes from the start oil had reached the top of the water-sands and was beginning to accumulate upon the water above. This shows that the zone of finer sand was no serious impediment to migration; it merely decreased the rate of migration slightly.

At the end of 14 hours migration had practically stopped, leaving a large amount of oil trapped in the water-sands.

The use of the elevated reservoir for forcing water through the sands was discontinued at this stage of the experiment, and the pressure bottle substituted, because with the latter the rate of

flow could be more easily regulated. Water was now forced through the tube for a few minutes at the rate of 90 c.c per minute, in order to dislodge and remove any globules of oil that were not tightly trapped. This rejuvenated migration for a few minutes, but soon it practically stopped. The rate of flow of water was then reduced to 28 c.c. per minute, and a stream of air bubbles forced in through a capillary opening at the same time. Active migration of a different type was immediately started. This was continued for 3 hours. At the end of this period a large part of the oil appeared to have been removed from the water-sands, though the latter were still liberally flecked with oil globules. Migration was still taking place when the experiment was stopped, and there is little question that in the course of time most, if not all, of this oil would be removed, since there seems to be no reason for its remaining. It would seem to be merely a question of getting a sufficient number of air bubbles in contact with the oil. It is probable that the air followed more or less definite routes in its passage through the sands, and therefore came into contact with only a part of the trapped oil.

Upon opening the tube the grains of the oil-sand were found to have an oil coating, but no oil-filled pores were noticed. The water-sands were found to contain an unexpected amount of oil in the pores and this oil seemed to be nearly uniformly distributed in the cross-section of the tube. This oil occupied pores but did not wet the sand grains—the latter were coated with a film of water.

Whenever air bubbles occur in water in the presence of oil, a film of the latter is adsorbed on the bounding surface between water and air (called the water-air interface). When an oil globule comes in contact with a water-air interface, the surface tension of the oil is overcome and the globule spreads into films. The air bubbles, being extremely mobile, pass through very small interstices in the sands under the propulsion of water pressure with great ease, and thus carry the oil films along. The amount of oil that an air bubble will carry in this way is considerable.

and as a result the bubbles are usually dark brown in color. Some of this oil, after being released from its trapped position by the air, later forms into globules again, and thus there is set up a combination of migration by films and by globules.

Experiment 8.—Object: To see if oil will migrate up *very low* dips under the propulsion of moving water and gas. Loading: The same as in Experiment 7.

The tube was inclined at an angle of 1 degree, but otherwise was treated as in Experiment 7. The only apparent difference in the results obtained in the two experiments was that it took 66 minutes for the oil to migrate the length of the water-sands when the angle of inclination was 1 degree, and only 26 minutes when the angle was 10 degrees.

Experiment 9.—Object: To see if a hydrocarbon gas will aid migration in the same way that air does. Loading: 6 inches of oil-sand at the bottom; then 3 inches of water-sand No. 2; then 3 inches of water-sand No. 1; then 6 inches of water-sand No. 2; the rest of the tube was filled with water. This loading is the same as in Experiments 7 and 8.

The tube was inclined at an angle of 1 degree. By means of the pressure-bottle, water was forced through the tube at about 18 c.c. per minute, and at the same time a stream of bubbles of illuminating gas was forced in through a capillary opening. This was continued for 3 hours. At the end of the experiment a large amount of oil had accumulated upon the water above the sands, and the tube had the same appearance as at the end of Experiment 8.

It took 30 minutes for the oil to reach the top of the water-sands. There seemed to be no difference between the behavior of air and that of illuminating gas.

For a few minutes during the progress of the experiment the lower end of the tube was raised until the slope was reversed, and the oil made to migrate *down* the slope, both with and without the aid of gas.

After the completion of this experiment some of the oil-sand was removed from the tube and placed in a flask with a large

excess of water. The flask was shaken, to ensure a thorough mixture of the water with the sand, and set aside for 5 months. At the end of this period there was no apparent change in the sand; it was of the same brown color and it still repelled water. An examination under the microscope showed the sand grains to be liberally coated with oil. This leads to the conclusion that water will not displace an oil coating from sand surfaces. This conclusion is of vital importance in the consideration of the relation of capillarity to oil migration.

Experiment 10.—Object: A comparison of the efficiency of moving water alone as a propulsive force, with that of moving water aided by the presence of air bubbles. Loading: 6 inches of oil-sand at the bottom of the tube; then 12 inches of water-sand No. 2; the rest of the tube was then filled with water.

The tube was inclined at an angle of 10 degrees. By means of the pressure-bottle, water was forced through the sands at the rate of 12 c.c. per minute; if all the pores were open this would result in a velocity of about 3.5 inches per minute through the pores. Oil migrated the length of the water-sand in 47 minutes, and thereafter slowly accumulated on the water above. Migration was very sluggish, and was by a network of connecting channels following the larger pores, rather than by individual globules. A large part of the oil seemed to be trapped.

The tube was emptied and reloaded in exactly the same manner. Water was now forced through at the same rate as before, and at the same time a small stream of air bubbles was forced in through a capillary opening. Oil migrated the length of the water-sand in 16 minutes, and thereafter accumulated upon the water above very rapidly. It is quite apparent that the presence of air is a great aid to migration.

One of the peculiarities of gas-induced migration is that a gas bubble will not carry its load of oil indefinitely through the water-sands, but carries it a short distance and then loses it. This is shown by the fact that the gas leaving the water-sands is not tinged with oil until oil globules appear very near the top of the sands. This is somewhat surprising as an adsorbed film

is supposed to be rather tightly held. In all cases great care must be taken not to admit too much air, or the water will be driven from the pores and migration will cease.

Because of the curvature of the glass tube and the small size of the oil globules, it was impossible to obtain any satisfactory photographs showing the appearance of the water-sands while the migration of oil was in progress through them. A special apparatus with a flat glass front, and in which much coarser water-sand was used, was therefore constructed. Fig. 32 is a photograph of a section of this apparatus, and shows the appearance of the water-sand while oil was being forced to migrate through it by means of moving water. Though the oil globules and sand grains are much larger than in the actual experiments, the appearance is typical.

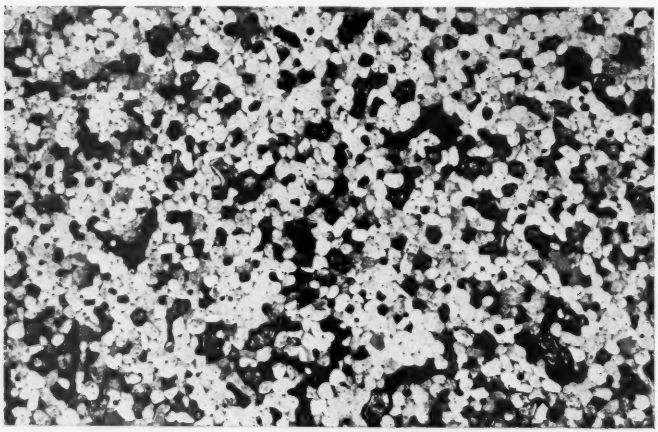

FIG. 32. Photograph showing the appearance of oil migrating through water-sand. Black spots, oil. White spots, sand.

DISCUSSION.

The object of these experiments was to study the lateral movement of disseminated oil through water-sands; the oil-sand was

merely used as a convenient source of such oil. The manner in which the oil was expelled from the generating shales into the water-sands is beyond the scope of this paper. Nevertheless, some of the observations made have a direct bearing upon the much discussed theory that oil is driven from the shales into the sands by capillary water; the idea being that water, having a greater surface tension than oil, has also a greater capillary pressure, and will, therefore, seize the finer openings and drive the oil into the coarser openings of the sands.

This theory is based upon a faulty conception of surface tension and capillarity. It is quite true that the surface tension of water against air is nearly three times that of oil against air, but the surface under consideration is the boundary between water and oil, which is a very different matter. The surface tensions of water against oil, of oil against water are identical, and, therefore, the capillary pressures of the two liquids would be the same if both liquids would adhere to the walls of the capillary openings. It is impossible, however, for both liquids to adhere to the sand grains; one of them must of necessity be present first, thus gaining possession of the sand grain surfaces. The other liquid will thereafter be repelled by these surfaces. The result is that the capillary pressures of water and oil are the same in magnitude, but in any particular sand one of them must be positive and the other negative. If the sediment particles have previously been wet by oil, the capillarity of the oil will be positive and that of water negative; oil will seize the smaller openings, and water will be forced into the larger. If the sediment particles have previously been wet by water, the reverse will be true. The experiments described in this paper have furnished evidence in support of this view, and some of Mills'[6] results also support it. There is nothing new in this; the fact that, whether the surface of a solid will attract or repel a given liquid depends upon the nature of the liquid with which the surface has previously been wet, has been widely utilized in the arts—lithography for instance.

[6] Mills, R. Van A., ECON. GEOL., vol. 16, 1921, p. 135.

Capillarity tends to keep oil in its original position rather than to cause movement. If the oil is expelled into a water-sand it will occupy the first pores it comes to, until compelled to move further by some force such as moving water. Unless propelled by some such force, it will not move from small to large pores, because the capillarity of the fine interstices between pores is an effective barrier.

When Munn[7] advanced the hydraulic theory of migration he thought that the oil was transported in the form of an emulsion (microscopic oil bubbles suspended in water) by water currents through the sands. We now know that the production of an emulsion is not possible unless an "emulsifying agent" is present; that the latter is always a colloidal substance; that the liquid in which the emulsifying agent is soluble, or by which it is the more readily wet, is always external, and, therefore, constitutes the suspending medium. Water-soluble colloids are extremely rare in ordinary natural waters, and the amounts are so minute, when found at all, that we are justified in assuming that an oil-in-water emulsion is not possible. Also, experience has shown that petroleum emulsions are always of the water-in-oil type. Except for some increase in viscosity, an emulsion of the latter type would behave in a manner identical with that of pure oil; in fact, the only apparent difference is in color.

In view of these facts we are forced to the conclusion that though the oil probably is generated in microscopic globules, the latter rapidly coalesce until they are of the size of the pores of the sand through which they are migrating. The same condition exists then as was established in these experiments, and the oil globules are forced onward by the pressure of the moving water, instead of being carried in the current in the form of finely disseminated bubbles.

The cause of the peculiar jerky motion with which the oil globules move from pore to pore was at first very puzzling, but there is no doubt that it is due to surface tension. As the surfaces of the sand grains are in the possession of water, capil-

[7] Munn, Malcolm J., ECON. GEOL., vol. 4, 1909, pp. 141–157; 509–529.

larity is negative to oil, and the globules of the latter are driven to the pore spaces where they assume as nearly a spherical shape as possible. It is a well-known fact that the pressure due to surface tension within a small bubble is greater than that within a larger one, and that, therefore, if the two are connected there will be a flow of fluid from smaller to larger.[8] A globule of oil will remain in a pore until the hydraulic pressure from below becomes great enough to distort it against surface tension to the dimensions of the outlet; it will then begin to pass slowly into the next pore, where a small bubble starts to form. There is now a small bubble of oil in each pore, and these bubbles are connected by a thread of oil through the interstice between the pores. As long as the upper bubble is the smaller, surface tension resists the hydraulic pressure and movement is slow, but as soon as the upper bubble becomes slightly the larger, conditions are reversed and the rest of the oil globule makes a sudden hop into the upper pore.

An oil globule will continue to travel through the sands in this manner as long as the pressure of the moving water is sufficient to force it through the interstices between pores; or in other words, as long as this pressure is greater than the negative capillarity of the oil for openings of the size of the interstices between pores. Of course these interstices between pores are not all of one size even in the same sand, and it is to be expected that a great many of them will be so small than an oil globule cannot be forced through except under excessive pressure, and that a large part of the oil will eventually be trapped. This is exactly what happened in the experiments. Gas bubbles, however, will pass most of these very small openings with great ease under the propulsion of the pressure of moving water, and carry their adsorbed films of oil with them.

It will be noted that great care has been taken to impress upon the reader that the gas and oil bubbles are forced forward by the pressure of *moving* water; this of course implies a greater pressure upon one side of the bubbles than upon the other. When

[8] See any textbook on physics.

these experiments were undertaken it was expected that gas bubbles would be found to be a carrier of oil even when water conditions were static. It was found, however, that the movements of oil and gas bubbles through water-sands are very similar; that the difference is one of degree only; and that the capillarity of the water in the interstices between pores is an effective barrier to migration in both cases unless some propulsive force other than buoyancy is applied.

No appreciable oil movements due to buoyancy were observed in these experiments, even when the oil was present in bulk. While Mills obtained satisfactory adjustments between water and oil by buoyancy alone, it must not be forgotten that he was dealing with almost vertical movements while these experiments deal with lateral movements.

CONCLUSIONS.

1. Buoyancy alone is too small a force to cause migration of oil or gas up low or moderate dips.

2. The difference in capillarity between water and oil is not a driving force.

3. Gas pressure alone will not move oil to any considerable distance, either in dry or moistened sands, unless the oil is present in large enough quantities to prevent the gas from blowing through, and then the movement is in mass.

4. The pressure of moving water will cause the migration of oil up any dip, or even down dips, provided the pressure is sufficient to distort the oil globules to the dimensions of the openings between pore spaces. The only resistance to this distortion (assuming viscosity to be negligible) is the tendency of the surface tension of the oil globules to keep them spherical.

5. Migration due to moving water is very much more active when gas bubbles are present. Part of the oil moves as films around the gas bubbles. This process is especially active in moving trapped oil globules.

6. There is very little frictional resistance to the movement

of oil through water-sands, because of the lubricating effect of the water. The resistance to movement is chiefly capillary.

7. Surface tension at the water-oil interface, and adsorption of oil at the water-gas interface, are factors of far more importance than has been supposed heretofore.

8. When water conditions are static, gas will not aid the migration of oil along low or moderate dips to any appreciable extent.

STATE AGRICULTURAL COLLEGE JUN 17 1922 LIBRARY

These experiments were suggested by C. F. Tolman, Jr., professor of economic geology, Leland Stanford Jr. University, and were conducted under his direction. Thanks are also due to Dr. Bailey Willis, professor of geology, for reading the manuscript and for valuable suggestions. Helpful discussions with several members of the physics department are also gratefully acknowledged.

DEPARTMENT OF MINING AND METALLURGY,
STANFORD UNIVERSITY.

A SUGGESTION FOR THE TERMINOLOGY OF CERTAIN MINERAL DEPOSITS.

WALDEMAR LINDGREN.[1]

A number of years ago I suggested that the ores which have been deposited by hot ascending waters fall naturally in three classes dependent upon the physical conditions surrounding their genesis.[2] Later on, this mode of subdivision was introduced in a textbook on "Mineral Deposits"[3] and it has since been adopted by other authors.[4] It was recognized from the start that the various classes were not sharply defined but gradually merged. On the other hand, the principle of classification seemed the only one suitable for a genetic system. It was also evident that the classification lacked a concise terminology and critics have not failed to emphasize this. While it seemed inexpedient to introduce new terms until the underlying principle was vindicated, the time for this introduction would seem to have arrived now, if acceptable names can be provided.

The general classification outlined in the work referred to has also been subjected to some criticism[5] on account of its alleged lack of strictly logical categories. This criticism may be well founded, but in the present state of our knowledge such a strictly logical system would be quite useless. There must be some elasticity, and exact definitions would only poorly veil our lack of knowledge as to the genesis of many deposits.

The terminology proposed would substitute definite terms for long descriptive statements and briefly stated would be as follows:

DEPOSITS OF ORIGIN DEPENDENT UPON THE ERUPTION OF IGNEOUS ROCKS.

A. Hydrothermal Deposits.

a. Epithermal. .....Formed by ascending hot waters near the surface in or near effusive rocks at relatively low temperature and pressure.

[1] Presented at the Amherst Meeting of the Society of Economic Geologists, Dec. 29, 1921.

[2] 10th Cong. Geol. Internat. Mexico, Pt. 2, 1906.

[3] Lindgren, W., "Mineral Deposits," New York, 1913.

[4] Ries, H., "Economic Geology," New York, 1916. Emmons, W. H., "Principles of Economic Geology," New York, 1918.

[5] Crook, T., *Min. Mag.*, London, vol. 17, 1914, pp. 55–85.

b. Mesothermal. .....Formed by ascending hot waters in or near intrusive rocks at intermediate temperature and pressure.

c. Hypothermal. .....Formed by ascending hot water in or near intrusive rocks at high temperature and pressure.

B. Emanation Deposits.

a. Sublimates. .....Formed by igneous emanations in effusive rocks near or at the surface at high temperature and low pressure.

b. Exudation Veins. (surface type) .....Small local veins in effusive rocks formed by igneous emanations at high temperature and low pressure, *e.g.*, tin veins in rhyolite.

c. Pyrometasomatic Deposits..Equivalent to "contact metamorphic" deposits. Formed by metasomatic changes in rocks, principally in limestone, at or near intrusive contacts, under influence of magmatic emanations, Temperature and pressure high.

d. Exudation Veins. (Deep seated type) .....Small local veins in intrusives. Formed by direct emanations at high temperature and pressure. Connects by transitions with hypothermal veins.

C. Magmatic Deposits.

a. Orthotectic.[6] .....Genesis by direct magmatic processes. Differentiated product poor in mineralizing fluids.

1. Differentiated in situ, *e.g.*, chromite deposits.
2. Injected, *e.g.*, dikes of magnetic or ilmenite.

b. Pneumotectic.[6] .....The differentiated fluid is rich in mineralizers.

1. Differentiated in situ. An uncommon type.
2. Injected. Exemplified by pegmatite dikes and by injected sulphide deposits. Sudbury would probably fit in here. These deposits form transitions to the hypothermal veins.

The terms epithermal, mesothermal and hypothermal are in close analogy with Grubenmann's three metamorphic zones, but do not exactly correspond to them. The prefix "hypo" has been substituted for "kata" to correspond with Ransome's now generally accepted terms of "hypogene waters," the suggestion implied being that the hypogene waters are principally derived from

[6] The terms "orthotectic" and "pneumotectic" have recently been proposed by L. C. Graton and D. H. McLaughlin, ECON. GEOL., vol. 13, p. 85, 1918.

the region of the hypothermal deposits. It is not desired to imply that such waters are necessarily wholly of magmatic origin.[1]

It is important to note that the hypothermal deposits form the transition link towards the deep-seated emanation deposits and towards those of the magmatic type.

In regard to these hypothermal deposits it should be emphasized that temperature is the dominating factor, though it is nearly always accompanied by high pressures. A deposit is of high temperature origin if noteworthy quantities of any of the following minerals occur in it: Pyrrhotite, magnetite, spinel, soda-lime feldspars, amphibole, pyroxene, biotite, topaz, tourmaline, axinite and garnet. Epidote and specularite generally, but not always, indicate such origin. The absence of the minerals enumerated does not positively indicate a lower temperature, for only persistent minerals like pyrite, chalcopyrite and quartz might be present. Usually some of the high temperature minerals are present in the altered wall rock at least.

Many mineral deposits have been altered by other agencies since their original formation. Such might be referred to as reworked deposits. An incomplete list of these would include:

A. Metamorphic Deposits.	Altered by processes of metamorphism.
a. Dynamometamorphic Deposits.	Altered by deformation. New minerals formed in part.
b. Pyrometamorphic Deposits.	Altered by contact metamorphism but without introduction of new substance. *e.g.*, a sedimentary limonite deposit altered to magnetite.
B. Supergene Deposits.	Old deposits altered by descending surface waters. Often two zones may be distinguished in these which may be called, respectively, the *oxysupergene* and the *sulphosupergene* zone according to whether oxysalts or supergene sulphides predominate.

Laboratory of Economic Geology,
Mass. Institute of Technology.

[1] A new nomenclature has quite recently been proposed by P. Niggli (Schweiz. M. & P. Mitt., Vol. 1, pp. 392–408) based in part on Bergeat's terms "peri-magmatic" (contact metamorphic) and "apo-magmatic" (ascending magmatic waters). While recognizing the value of these terms, I prefer not to use them, owing to the difficulty of recognizing what is "apo-magmatic" and what is not.

EDITORIAL

INDUSTRIAL COMPANIES AND PUBLICATION.

In our last number we took the liberty of calling attention editorially to the duty which economic geologists owe to their colleagues, of adding to as well as extracting from the literature of economic geology. But that is only one side of the story. The geologist himself may be perfectly willing in this matter; but in the case of those employed by industrial companies, he may be prevented or retarded by the company policy of not allowing any information to be released. For the fullest exchange of information and ideas by means of the printed page there must be cooperation on the part of the companies as well as on the part of the geologists in their employ. We appeal for such release of scientific information by the executives of industrial companies, not only from the altruistic standpoint of rendering available to science valuable geologic data, but also that they themselves may profit by the information liberated by another company.

Industrial companies which employ geologists have in the past been none too free in granting permission for the release of scientific data. Of late, however, we have noted a change for the better in this respect, and we are glad to record that small efforts on our part aimed toward the dissemination of specific geologic data have met with pleasing response. The petroleum industry perhaps more than the mining industry has shown progression in this matter. Nevertheless, as compared with other industries employing scientists, such as chemistry, electricity, and metallurgy, there has not been the equivalent release of data, and no one will deny the advantages which have accrued by the broad publication of information relating to the latter.

We appreciate only too clearly the necessity of withholding certain information and the disastrous effects that may sometimes attend the uncautious publication of confidential information or

results. It is not for such that we make our plea, but rather for the liberation of valuable scientific data which oftentimes may so readily be culled from the commercial phases which of necessity must be kept confidential, or for those data which through the lapse of time have lost their commercial significance and still are valuable to science as geologic truths. This refers to both mineral deposits and petroleum.

The great advance in exchange of ideas relating to the technology of mining and petroleum, as may be seen in our contemporary engineering journals, has proved of immediate help to others in the same field. Similarly, a greater exchange of geological information should prove equally helpful, though with a greater lag in the time of benefit. Idea stimulates idea and data given brings a return of data from others which may prove helpful in formulating conclusions. In addition to the individual material benefits, there is the greater opportunity of helping to build up the fundamentals of geologic science by liberating much locked-up material. We have heard that in discussion between a leading consulting petroleum geologist and one of the prominent members of the United States Geological Survey it was agreed that about seventy-five per cent. of the funds spent upon geologic investigation in the United States emanated from commercial companies. This means, then, a wealth of material relating to economic geology, most of which is inaccessible. Obviously not all of this would be either available or desirable for publication, but unquestionably there is among it much that would be.

Not only do we urge more extended permission to release locked-up geologic information of scientific nature on the part of industrial companies, but we ask that they go even further and encourage and give opportunity to the geologists in their employ to bring this about.

ALAN M. BATEMAN.

DISCUSSION
AND
INFORMAL COMMUNICATIONS

This department is maintained in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion or communication. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters of geologic interest not previously treated. Letters should be directed to Alan M. Bateman, Editor, Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE VEINS OF COBALT, ONTARIO.

Sir: Geology is being split up into highly specialized departments and it is hardly to be expected that men admirably equipped in one department should be familiar with the later developments of other departments. A man may be an excellent mining geologist and yet be unfamiliar with the known conditions of glaciation.

Some time ago I had to criticize the statements of W. L. Whitehead (ECON. GEOL., Vol. XV., p. 539), opposing the glacial origin of the Cobalt conglomerate, and showed what all glacial geologists are agreed upon regarding its formation. In your number for December, 1921, A. R. Whitman came to the defense of his assistant, but did not improve matters from the glacial point of view. After mentioning that residual soils in some places underlie the Cobalt conglomerate, he states that "Residual soil of Preglacial age is thus far unreported from the surface overridden by the Pleistocene glaciers of Ontario; and the till which they produced is less in thickness than that produced by the supposed Huronian glaciers."

Residual soil has been found in a number of places in Ontario; it has been mentioned, for instance, from Slate Island, and Michipicoten, Lake Superior, where thousands of feet of ice are

known to have filled the basin. Residual soil is described by Taylor[1] at Niagara; and no glaciated surface, only weathered shale, has been found under the boulder clay at Toronto. The fact is that geologists have been impressed by striated rock surfaces, but have seldom paid attention to weathered materials in glaciated regions. From the dynamical point of view glaciers scour only under suitable conditions; they deposit near their borders, and the greater their load of boulder clay the less ability they have to erode or striate rock surfaces. Glaciers, like rivers, deposit materials instead of removing them where their motion slackens. Where boulder clay, ancient or modern, is thick, striated rock surfaces are not to be looked for. For example, the northern Dwyka conglomerate is thin and overlies *moutonnées* surfaces, but over thousands of square miles toward the south, where the tillite is thick, no polished or striated rock surface has been found. Much of the thick tillite of Permo-carboniferous age in Australia has no striated surface beneath it; and the same is true in southern Brazil, where weathered material underlies the tillite. No striated surface has been found by Howchin under the thick early Cambrian tillite of south Australia.

Miller and myself have found smoothed rock surfaces under the Cobalt tillite, but no striæ have been reported. One may close this part of the discussion by saying that a striated surface beneath a tillite is welcome evidence of ice action, but that weathered and unstriated floors afford no evidence against ice action, particularly when the boulder clay is thick.

Whitman's suggestion that the Timiskaming mountains provided sufficient slopes for torrents to form the hundreds of square miles of Huronian tillite seems entirely without geological support. There were Timiskaming mountains, but all the evidence shows that they had been destroyed and the surface reduced to a peneplain before the Cobalt conglomerate was formed. Wherever this conglomerate has been found, at Cobalt, at Timagami, on the shore of Lake Timiskaming, at Chibougaman, at Sudbury, or in the original Huronian region, it rests on the upturned edges of

[1] U. S. Geol. Surv. folio—Niagara, p. 16.

the more ancient rocks. Over all the thousands of square miles where large areas or small patches of Cobalt conglomerate are found the floor on which they rest has a flat or gently undulating surface. The mountains down which the torrents were to flow had ceased to exist before the Cobalt ice sheet began its work.

JUN 17 1922

Neither of the two lines of argument brought forward to oppose the glacial origin of the Cobalt boulder conglomerate has any weight. On the other hand, every feature of the tillite and its associated "varve" shales is exactly repeated by the later ice ages, especially those of the Permo-carboniferous and the Pleistocene. Hand specimens and thin sections of the Cobalt tillite are indistinguishable from those of the South African Dwyka or the tillite of Sierra de la Ventana in Argentina. If Messrs. Whitehead and Whitman will do me the honor to call, I shall be glad to show them evidence that has satisfied all the glacial geologists who have studied the materials at the Royal Ontario Museum, Toronto.

A. P. COLEMAN.

UNIVERSITY OF TORONTO,
CANADA.

Sir: The paper by John W. Gruner, "Paragenesis of the Martite Ore Bodies and Magnetites of the Mesabi Range," in ECON. GEOL., Jan.–Feb., 1922, describes some features of the early history of the district that are of interest to the student of iron ores in general as well as of the Lake Superior deposits in particular. That magnetite has played a considerable part in the development of the hematites on the Mesabi range through its contribution of material to the formation of the high-grade blue ores, which are essentially pseudomorphic martite, puts a somewhat different aspect on the methods of ore concentration as worked out in the earlier reports, if it does not call for a material modification of theory.

The large-scale alteration of magnetite to martite described by Mr. Gruner is a problem in itself, about which perhaps the final word has not yet been said. Instances of the kind are rare, even very exceptional, if we consider the wide distribution of the min-

eral and the many hundreds of deposits which have been described at one time or another. In the present occurrence the change appears to have taken place only in proximity to or within the main ore zone where oxidation and weathering have been at work. To these influences is ascribed the breaking down of the magnetite which seems to have been in progress in the later period of ore concentration. It is regarded simply as one phase of the work of cold meteoric waters which dissolved and precipitated the iron supplied by greenalite and at the same time removed enormous amounts of silica, that is, if I understand the author correctly.

The breaking down of the magnetite is admittedly an oxidation process, but it is questionable perhaps whether meteoric waters unassisted by any external contributing agency or whose oxidizing powers have not been increased beyond that natural to ordinary superficial circulations in crystalline formations would accomplish the indicated results on a most liberal basis for time. An alternative would appear possible—that the meteoric waters, which primarily may have been only weak solvents, received their main chemical properties from a deep-seated source. That this is not altogether improbable is shown by the development of magnetite, as we know now, during an interval in the progress of the hematite concentration, for it both replaces an earlier generation of hematite and is itself altered to hematite. Its production involved metamorphic influences, regional or perhaps igneous metamorphism from a source below the iron-bearing beds.

Magnetite is extremely stable under surface conditions. It stands up indefinitely in the presence of cold oxidizing solutions, as shown by its presence in old sandstones and by its behavior in the outcrop of deposits that have been exposed practically in their present position since early geologic times. On the latter point I may cite many occurrences in the Adirondacks whose outcrop was planed off in pre-Cambrian time, and the original surface is now exposed almost unchanged through removal of a veneer of Potsdam sandstone by the Pleistocene ice sheet. There is no indication of alteration of the magnetite in most of the occurrences,

but in one or two that will be mentioned presently the magnetite has been partly or mostly converted to martite. To be sure, it requires only a small amount of oxygen to change magnetite to hematite, but the process is extremely slow under ordinary conditions. Under surface conditions one would expect the product normally to be limonite rather than hematite.

The single occurrences of martite in the Adirondacks, where the mineral is at all common, are in the Arnold Hill district of Clinton County. Two or three bodies within the district have been so altered as to have a blue color and contain so much martite that the usual magnetic methods of mill treatment involve large losses of iron. Such bodies are sporadic in occurrence and are accompanied by deposits in the near vicinity that have undergone little or no change. The martite is not a superficial development, but extends downward on the dip of the deposits to the limits reached in mining, which I believe is about 800 feet. The ore carries more or less fluorite, jasper, quartz, and calcite in small veins that are seldom seen in other bodies where the magnetite is unaltered. Study of the physical characters and structure of the ore bodies gives no clue to the selective oxidation shown by the magnetite, and the only explanation I have been able to find is connected with intrusions of trap (diabase) dikes, of which great numbers are found in this part of the Adirondacks. They cut and not infrequently fault the magnetite deposits; the time of their intrusion may be put in the late pre-Cambrian, but before the region was finally leveled off and began to be encroached upon by the Cambrian sea. Altogether they indicate a magmatic reservoir of generous proportions somewhere below the existing surface. It is quite apparent from the conditions that the distribution of martite is not related to recent weathering, and while there is not sufficient evidence to establish a direct relation between the igneous invasions and the oxidation process, this seems at least quite plausible. I would not say that the change is a contact effect, but rather the result of some solvent or catalytic agent released by the magma in its upward progress.

I may note that the altered ores on Arnold Hill contain small amounts—a few hundredths to tenths of a per cent. usually—of nickel and copper. These are not present in the unchanged magnetites, so far as my knowledge goes, or elsewhere in the Adirondack deposits except in the magnetite-ilmenite mixtures of the very basic magmas. The titaniferous ores, to be sure, carry only small amounts.

D. H. NEWLAND.

ALBANY, N. Y.

REVIEWS

The Microscopic Determination of the Non-opaque Minerals. By ESPER S. LARSEN. 294 pages. U. S. Geological Survey Bulletin, 679, 1921.

For the determination of the metallic minerals the blowpipe has long been available, and in recent years the development of mineragraphy has permitted the recognition of the constituents of fine-grained mixtures. Many of the non-opaque minerals, however, are difficult, if not impossible, to identify by these methods, and it is to them that the immersion method is applicable. Tables for use with this method have been available for some years, but they have included only the commoner minerals, and some of the data have been inaccurate, while the arrangement has not always been convenient. To remedy this situation, Dr. Larsen has collected more complete information, determining the optical constants of over 500 species, and has now presented the results in a very usable form.

With liquids of known refractive indices—which are now on the market—and a simple petrographic microscope, it is possible to place practically any unknown mineral quickly and certainly. It is necessary merely to ascertain first the optical class, isotropic, uniaxial + or —, biaxial + or —, and one or two of the refractive indices, by finding liquids in which the grains disappear, and then, by running through the tables, in which arrangement is simply in the order of increasing index in each class, the mineral can usually be definitely located. It must be constantly remembered, however, that many minerals vary in composition and accordingly in indices, so that one should consider species for some distance on either side of the observed intermediate index of the unknown before reaching a final conclusion.

A glance through "Larsen's Tables" shows many minerals of interest to the economic geologist to be included, and the possibilities of the application of this method are evident. It may permit, for instance, the identification of secondary oxidation products far too minute in amount to study by any other method, indirectly throwing some light on the metals present in a given ore, or the recognition of the nature of silicate minerals which crumble from the edge of a chip being prepared for mineragraphic study. Every one who has mineral identifications to

make will be heartily thankful to Dr. Larsen for this valuable piece of work.

EDGAR T. WHERRY.

BUREAU OF CHEMISTRY,
WASHINGTON, D. C.

Introduction to the Study of Minerals and Rocks. A combined Textbook and Pocket Manual. By AUSTIN FLINT ROGERS, Ph.D., Professor of Mineralogy, Stanford University. Second Edition, 1921. McGraw Hill. 12mo, 527 pages, 578 illustrations.

The present volume, while of handsome appearance, does not, as regards the style of binding employed, come up to the usually high standard maintained by the publishers. Its covers consist of thin, unsubstantial cardboard overlaid with red cloth, so that a slight accidental bending will result in permanent damage to the book. It would appear from the purposes this book is intended for—field and laboratory—that an especially rugged type of binding were needed to stand the ravages of a laboratory table or often damp field quarters. The execution of the printed part of the book, however, leaves little to be desired. The paper is good, the illustrations clear and the type employed, as well as the arrangement of the matter under bold-faced subtitles, makes easy reading.

As the change in title suggests, this second edition represents an enlargement in scope of the first, published under the name of an "Introduction to the Study of Minerals." A description of the Mineraloids has been added to Part II., the space devoted to the Determination of Minerals greatly increased, and Part III., treating of the Occurrence, Association and Origin of Minerals, nearly quadrupled in volume by the addition of petrological descriptions. On the other hand, Part VII. of the first edition discussing the Uses of Minerals has been eliminated, but the subject matter incorporated with the descriptions of the individual minerals. The Glossary of the first edition is replaced by a much condensed index and glossary combined.

The author divides the book into four parts of which the first, comprising 207 pages, deals with the properties of minerals, the second, 206 pages, with the description of important minerals and mineraloids, and in the third and fourth parts respectively the occurrence, association of minerals, 47 pages, and the determination of minerals in 45 pages. Taking them up in order, Part I. is treated under three subheadings: "Chemical Properties" in which the elementary principles of Chemistry are briefly reviewed, iso- and polymorphism discussed and the apparatus, reagents and various tests used in blowpipe analysis de-

scribed. Its mode of treatment does not differ from that of the standard texts on Mineralogy. The second subhead on the morphological properties of minerals deals rather fully with the symmetry, forms and general properties of crystals, notation and drawing of crystal faces, classification, cleavage and twinning. Profuse illustrations aid the text which ends with a discussion of the internal crystal structure, based on the work of Lane, the Braggs and others. Under "Physical Properties," the third subdivision, are given the simpler ones, such as specific gravity, hardness, luster, etc., and the optical properties, commonly grouped under the subject name of "Optical Crystallography." The author apparently expects the student to have good grasp of "Optics" since it is certain that, lacking it, he will gain little, if any, profit from reading the text. The proper treatment of an admittedly elusive subject such as the Fresnel Ellipsoid, for instance, surely calls for more than two and a half short pages and one illustration. The remainder of this chapter is devoted to tables of refractive indices, etc.

Part II. gives descriptions of the 175 minerals selected by the author for their economic, scientific or geological importance, each mineral being treated under subtitles, as form, hardness, color, optical properties, chemical composition, blowpipe tests, specific gravity, special distinguishing features, its uses and geological and geographical occurrence. Representative analyses are sometimes appended.

In the first five pages of Part III. the general principles guiding the association and order of succession of minerals are laid down, the natural as well as the various synthetic processes of mineral formation and their alteration and replacement briefly touched on. This is followed by about thirty-five pages of elementary petrology including a short discussion of regional, contact, and hydrothermal metamorphism. The various rocks are differentiated by their macro- as well as microscopical characters and some of their occurrences briefly indicated. The subject of Ore Deposits is disposed of in five and a half pages under the subtitles of High, Intermediate and Low temperature deposits, Supergene Enrichment and Zone of Oxidation. This may well have been omitted. As the sub-titles suggest, it abounds in, for a beginner, needless technicalities and lacks in the broadly descriptive treatment so essential in an elementary course.

Part IV. is wholly devoted to the determination of minerals by means of tables, giving their physical, chemical and optical characteristics, to be used in conjunction with Part II. where the various minerals are described in detail.

While the author, in the execution of this work, may have been guided mainly by his own teaching requirements, it is safe to say that

most universities do not attempt to crowd elementary mineralogy, optical crystallography, petrology and petrography into one year's undergraduate work such as the author intends this text for, according to the preface. His endeavor to cover as wide a range of subjects as possible and keep within the projected bounds of this volume at the same time has evidently resulted in the fatally brief and insufficient treatment of some of the chapters, as already pointed out. On the other hand, such themes as crystal structure, or the Inversion Chart of Quartz, while certainly of interest, should have no place in an elementary text. Too great a wealth of detail offered in such a book frightens the average student, obtaining his first impression of the science. As a pocket manual, to be used in the field, it may come in handy, but its small number of minerals selected by the author and the general, rather cumbersome arrangement of the Determination Tables would render its possession in the field of doubtful value.

P. ARMSTRONG.

Petrographic Methods and Calculations. With some examples of results achieved. By ARTHUR HOLMES. 506 pp., 83 figs., 4 plates. Thos. Murby & Co., London. Price, $6.00.

Dr. Holmes's book should be a welcome addition to the library of the petrographer, the economic geologist, and the microscopist engaged in research. It presents to the petrographer and economic geologist in a comparatively simple way the most modern methods of attacking many of the problems that are constantly confronting them, and points out to the chemist and the engineer "that the methods of work devised by the petrologist are competent to attack many of the problems with which they are faced."

The excellent treatises of Wright and Johannsen are not superseded by Holmes's book. The volumes cover different fields. Wright and Johannsen deal with refined microscopic methods for determining the optical properties of individual crystals. Holmes's volume outlines all methods that may be employed in determining the characters of crystals and of crystal aggregates, whether they be rocks or industrial products, and of aggregates of loose grains. Only 52 pages are devoted to the determination of the optical constants of crystals, but all the methods of most practical importance for this purpose are briefly, though accurately, described. The greater part of the volume deals with methods that are merely referred to in the textbooks of petrology and for the description of which the student must often search far and wide. They have all been collected by Dr. Holmes and made conveniently accessible. Footnotes call attention to the original articles where the discussions of the methods are given

more fully. A notable feature of the book are the many illustrations of the applications of the methods in actual investigations.

It is plainly impossible in a brief review to name all of the many methods described in a volume like the one under discussion. Perhaps it will give an idea of the comprehensiveness of the book if the contents of the different chapters are enumerated.

Chapter II. deals with specific gravity, porosity, absorption, and molecular volumes.

Chapter III. outlines the methods employed in the separation of grains by water currents, vibration, heavy liquids, magnetism, and chemical reagents.

Chapter IV. describes the use of the microscope in determining the size, thickness, and optical constants of grains, including a rather thorough description of methods for determining indices of refraction by immersion.

Chapter V. discusses the examination of detrital sediments and shows how the source of a sand may often be learned by studying the result of a careful separation of its components. This chapter should furnish suggestions to geologists who are engaged in studying the characters of oil sands.

Chapters VI. and VII. tell of the methods of making thin sections and micro-chemical and staining tests. Only those tests that have proven satisfactory are described. Some of them are unfamiliar to the American student, so that their discussion is very welcome.

Chapters VIII. and IX. are devoted to the methods of studying the associations of minerals in thin sections, their relative proportions, and the characteristic features of various rock structures.

Chapters X. and XI. deal with the chemical characters of rocks. Chapter X. discusses the way in which a chemical formula is calculated from an analysis and outlines the method of calculating a rock norm, while Chapter XI. shows how compositions may be represented by diagrams, and how these may be employed in reaching conclusions.

The four plates illustrate the characteristic features and structures of sedimentary, igneous, and metamorphic rocks.

In one or two places the directions for following methods of calculations are not quite clear, because too concise, but on the whole the descriptions of manipulation are excellent.

W. S. Bayley.

SOCIETY OF ECONOMIC GEOLOGISTS

This department has been established for the official communications of the Society of Economic Geologists whereby the affairs of the Society such as notices, minutes, titles of papers, elections, etc., may be brought regularly to the attention of its members.

Dr. E. C. Harder has been appointed Chairman of the Royalties Committee resulting from the sale of "Political and Commercial Geology" by J. E. Spurr and his 29 collaborators. The royalties total more than enough for a scholarship in Political and Commercial Geology for the college year 1922–1923. Applications for this should be sent to the Committee on Royalties, E. C. Harder, Chairman, 1111 Harrison Building, Philadelphia, Pennsylvania.

The next Annual Meeting of the Society will be held at Ann Arbor, Mich., as guests of the University of Michigan from December 28 to 30, 1922. Titles of papers to be submitted should be sent to B. S. Butler, Chairman of the Publications Committee, in care of Calumet and Hecla Mining Co., Box 277, Calumet, Mich.

Members expecting to attend the Scientific Congress of the Association des Ingenieurs at Liege, Belgium, should kindly inform the Secretary.

The Committee to nominate officers for 1923 consists of the following:

H. Foster Bain, *Chairman,*
Alan M. Bateman,
E. De Golyer.

SCIENTIFIC NOTES AND NEWS[1]

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

S. R. Capps, of the U. S. Geological Survey, sailed May 5 for the Near East to engage in foreign Petroleum work.

D. H. McLaughlin sailed for Peru, after a two months' vacation, to continue his work as chief geologist for the Cerro de Pasco Copper Corporation at La Oroya, Peru.

C. E. Siebenthal, of the U. S. Geological Survey, is at Miami, Oklahoma, in the Joplin district.

G. F. Loughlin, of the U. S. Geological Survey, is in Leadville, Colorado, completing details connected with the Leadville monograph.

Charles Camsell, of Canada, has been awarded the Murchison grant by the Royal Geographical Society of Great Britain, in recognition of distinguished service in exploration.

H. G. Ferguson and S. H. Cathcart are in Nevada, mapping the Tonopah Quadrangle for the U. S. Geological Survey.

F. A. Carlson, Instructor at Cornell, has been appointed Assistant Professor of Geology in the Northern Branch of the University of California.

W. T. Lee is in southern Wyoming, continuing his studies of the stratigraphy of the oil sands.

D. F. Hewett, of the U. S. Geological Survey, spent the middle part of May at Fallon, Nevada, investigating reports that oil has been struck in a number of wells in the vicinity of Fallon.

W. H. Goodchild has left for a short trip to Burma.

J. S. Brown has been appointed Emmons Fellow for the ensuing academic year and expects to carry on investigations at Columbia University on the graphite deposits of Alabama.

H. Foster Bain, Director of the U. S. Bureau of Mines, is in Alaska to witness tests of coal from the Chickaloon and Bering River fields to determine their fitness for naval use. He visited on the way the experiment stations of the Bureau at Urbana, Denver, San Francisco, and Seattle. He left Seattle on May 17, going on to visit Governor Bone at Juneau, from there to Seward and Sutton for the coal tests, and traversing the region covered by the Alaskan railroad.

G. R. Mansfield, of the U. S. Geological Survey, has been placed in charge of the section of non-metalliferous deposits.

J. D. Sears, James Gilluly, and W. H. Bradley, of the U. S. Geological Survey, are carrying on geological mapping in Moffat County, Colorado.

A. J. Collier has arrived in Avon, Montana, to study the oil geology of the field in which a strike was recently made by the Gordon-Campbell well.

Percy E. Hopkins, of the Ontario Department of Mines, is examining the gold areas east of Kirkland Lake.

A. E. Fath and W. W. Rubey are examining for the U. S. Geological Survey the stratigraphy, structure, and oil prospects of a belt in eastern Wyoming bordering the Black Hills, a project started two years ago by A. J. Collier.

A. J. Bancroft, professor of geology at McGill University, Montreal, who has been on leave of absence for one year to occupy the position of assistant manager of the Granby Company at Anyox, B. C., is to return to his duties at McGill next September.

T. M. Bains has accepted a position as geologist with the Moctezuma Copper Company, Pilares de Macodari, Sonora, Mexico. He was formerly assistant professor of metallurgy at the Missouri School of Mines and Metallurgy at Rolla, Missouri.

A. F. Melcher, of the U. S. Geological Survey, has gone to the Burbank field in Oklahoma to obtain material for studies of porosity of the oil-producing sands.

J. A. Burgess has been making a geological examination of the Comstock Silver property on the Comstock.

C. E. Dobbin, assisted by A. H. Redfield and J. E. Hoffmeister, of the U. S. Geological Survey, is continuing his work on the coal fields of Garfield County, Montana.

C. D. Avery is visiting Moorcroft and other points in eastern and central Wyoming to obtain data on the development of a number of oil wells for the U. S. Geological Survey.

Nevin M. Fenneman, Professor of Geology and Geography at the University of Cincinnati, has been elected Chairman of the Division of Geology and Geography of the Natural Research Council.

H. C. George, of the petroleum division of the U. S. Bureau of Mines, has gone to Alaska.

M. C. Lake, chief geologist for M. A. Hann & Company, has been at Ironwood, Michigan, examining the Ashland mine.

F. L. Hess, of the U. S. Geological Survey, is at present in the field gathering data for the Division of Mineral Resources.

R. J. Parker, mining engineer, returned to Denver, Colorado, recently from the Belgian Congo.

P. G. Morgan, Director of the New Zealand Geological Survey, is now making an examination of the Waihi Goldfield.

Hewitt O. Fearn, mining engineer, has left for Maracaibo, Venezuela, on oil exploration.

Henry A. Ley, formerly geologist for the Sun Company at Dallas, Texas, is now chief geologist for the Southwestern Gas Company of Independence, Kansas.

The U. S. Geological Survey has sent a party to carry on a topographic and geologic survey in the Cold Bay oil region, Alaska. The geologic work will be done by A. A. Baker and W. R. Smith, and the topographic work will be in charge of R. H. Sargent.

H. W. Turner is engaged in professional work in Inyo County, California.

The U. S. Geological Survey announces the discovery of notable amounts of potash in a new area, the southwest corner of Regan County,

KANSAS STATE AGRICULTURAL COLLEGE
JUN 17 1922
LIBRARY

Texas, obtained from Santa Rita No. 1 Well of the Texan Oil and Land Company.

Members of the Geological Department of Cornell University will be occupied at field work during the summer as follows: Prof. Ries and C. M. Nevin, investigating the sand resources of Virginia; O. G. Bell, in Florida, working on clays and foundry sands; J. L. Stuckey, in North Carolina, engaged in a study of the pyrophyllite deposits.

Raphael Ed. Liesegang, Professor of the Institut für physikalische grundlagen der Medizin, Schloss Str. 21, Frankfurt am Main, who is well known for his studies of diffusion and of the phenomena generally referred to as "Liesegang rings," requests that geologists who may publish, or who have recently published, papers dealing with the relation of ore deposition to colloid chemistry or diffusion will forward to him copies of their works. He explains that he desires these for abstracting for the "Kolloid Zeitschrift" and for use in the preparation of new editions of his books on Geologic Diffusion in Agates. The present postage rates from Germany prohibit personal requests, and those who send him their publications will aid in this useful work.

The Oklahoma Academy of Science had its 10th Annual Meeting at Oklahoma City February 10 and 11, at which the following geological papers were read: Physiographic History of the Arbuckle Mountains, by S. Weidman; Some Observations of Erosion and Transportation in the Wichita Mountain Area, by Oren F. Evans; Subsurface Studies, by R. D. Reed; An Oklahoma Meteorite, by A. C. Shead; Robberson Oil Field, by Leon English; Percentage of Square Mile of Oil Production in Oklahoma, by Besse M. Mills; Oklahoma Oil Resources, by C. W. Shannon; A New Variant of the Hidden Treasure Myth, by C. H. Gould; The Webber's Falls Limestone, by J. B. Thoburn; Sykes Alaskan Expedition of the University of Oklahoma of 1921, by Ed. Crabb.

Herbert N. Witt is consulting geologist with Thebo, Starr and Anderton of San Francisco.

Dean E. Winchester has opened a consulting office in Denver, Colorado, to handle geological investigations of petroleum, oil shale and coal properties.

L. Reinecke expects to practice in Johannesburg in the near future as a mining geologist and topographer. At present, his address is Ceres, Cape Province, South Africa, in care of Rev. D. M. Reinecke.